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PETROLOGY, STRATIGRAPHY, AND ORIGIN OF THE TRIASSIC SEDIMENTARY ROCKS OF CONNECTICUT

By

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Professor of Petrology and Sedimentation
The Pennsylvania State College

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Raymond S. Thatcher
State Comptroller.

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Professor of Petrology and Sedimentation
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(A Dissertation presented in 1936 to the Faculty of the Graduate School of Yale University in partial fulfillment of the requirements for the degree of Doctor of Philosophy)

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ABSTRACT

The present report describes the southern part of the Triassic area of the Connecticut Valley and the whole of the Pomperaug area.

The Connecticut Valley area is bordered on the east by a north-south trending major fault, the "Great Fault", downthrown on the western side and with a displacement of from 17,000 to 35,000 feet. The Pomperaug basin is a downfaulted outlier disposed thirteen miles west of the main area. The Triassic section dips 10° to 15° east and is broken up into numerous fault-blocks.

The Triassic sediments form a wedge-shaped sedimentary prism built up of ancient coalescing alluvial fans which radiate westward from the Great Fault. The thickness of the section near the Great Fault reaches 16,000 feet; in the Pomperaug area, 32 miles to the west, it decreases to less than 1,500 feet.

The Triassic section can be divided into three formations:

1. A lower unit, the New Haven arkose, up to 8,500 feet thick, a relatively coarse fluvial sediment, consisting of gray and pink arkoses, conglomerates, red feldspathic sandstones and subordinate red siltstones and shales.

2. A middle unit, the Meriden formation, up to 2,800 feet thick, a fine-grained series of lacustrine and swamp deposits consisting of variegated or dark-colored siltstones, shales, limestones, light feldspathic sandstones, subordinate coarser clastics, and three basaltic lava flows.

3. An upper unit, the Portland arkose, up to 4,000 feet thick, a fluvial deposit similar to the New Haven arkose.

The relative frequencies of nineteen non-opaque heavy minerals make it possible to divide these three formations into seven additional mineral zones. Red beds form 52 per cent of the section. Lithologically the section contains 10 per cent of conglomerates, 64 per cent of sandstones and arkoses and 25 per cent of siltstones and shales. Near the Great Fault the normal sediments pass into fanglomerates at all horizons.

Petrographically, the Triassic rocks consist of a mixture of three end members:

1. An arkosic (granitic) detritus made of approximately 58 per cent quartz, 40 per cent feldspar (31 per cent microcline, 9 per cent sodic-plagioclase) and 2 per cent mica.

2. A mixture of white and hematitic clay consisting of approximately 60 per cent kaolin, 6 per cent gibbsite, 12 per cent sericite-illite and 20 per cent hematite.

3. A calcite cement.

These three end members can mix in all proportions to form the following rock types: pale arkoses (gray to purplish gray or pale pink, rarely dark gray), red arkoses, brick-red clayey feldspathic sandstones or "Redstone", white non-clayey feldspathic sandstones, red siltstones, red shales, black shales and sandy limestones.

Two main groups of alluvial fans exist: A central Connecticut group characterized by indicolite, the scarcity of epidote and a relatively fine gross lithology; and a southern Connecticut group characterized by the absence of indicolite, the abundance of epidote and a relatively coarse gross lithology. The absence of lateral mineral contamination between these two fan groups suggests a persistent drainage on a westward slope. The drainage was disturbed only during Meriden time when a structural warping of the surface led to the formation of huge swamps. Almost all the sedimentary detritus was derived from a source area extending 3 to 10 miles east of the steep but moderately high Great Fault scarp, which was recurrently rejuvenated during Triassic time.

A critical evaluation of the genetic significance of climatic criteria precedes the paleoclimatic and paleogeographic interpretations.

Thick beds of red clay locally derived from a source area belonging to the same climatic province as the basin of deposition (as in the Triassic of Connecticut), huge swamp beds and the character of the flora suggest a heavy precipitation and a high temperature. Fresh, non-weathered arkose deposits and even fanglomerates do not disprove this, for they are known to form even in the equatorial rainforest if a steep topography favors violent erosion. A mixing of fresh and deeply decayed material is characteristic of sedimentation under a humid tropical climate in regions of steep topography, where torrents cut deeply incised canyons across the lateritic cover to erode fresh bedrock.

Desiccation marks, casts of soluble salts, abundance of fossil tracks and scarcity of skeletal remains indicate a marked dry season and also a high temperature but are nevertheless compatible (even halite crystals) with a high precipitation during the rainy season.

In conclusion it is suggested that the Triassic beds of Connecticut were deposited under a savanna climate, i. e., a tropical humid climate characterized by a high and constant temperature (possibly around 80° F.) and a heavy precipitation (above 50 inches) seasonably distributed, with a marked dry season of possibly three months' duration or more.

CHAPTER I

INTRODUCTION AND HISTORICAL REVIEW

Need For The Present Study

The Triassic arkoses and red beds of eastern North America represent one of the most extensive units of continental sedimentation known to geology.

Although the Connecticut Valley area of the Triassic perhaps was studied in more detail than any other Triassic basin, still the evidence available until the present time was based on field work and megascopic inspection rather than on detailed petrographic examination. Lack of precise petrographic knowledge of these interesting sediments has perforce made many of the earlier interpretations tentative.

A further obstacle to a proper understanding of the peculiar sedimentary processes of the Triassic period was the lack of knowledge of sedimentary and geomorphic processes outside of the temperate belt. Most of the present-day geologic analogies brought forth to explain Triassic sedimentation were largely based on examples located within the continental United States, such as the Great Valley of California or the southeastern Appalachian region. In the light of recent studies of sedimentary processes taking place in the Tropical Belt, until now but little known to geologists, a restudy of the red arkoses of the Triassic through the application of detailed petrographic methods appeared to be desirable.

Scope of Work and Acknowledgements

The present investigation was begun in the fall of 1931 and completed in the winter of 1935. Most of the field work was done in 1934, parts in 1933 and 1935. The laboratory work was carried on during the academic years of 1933, 1934 and part of 1935. During that period the writer worked under the supervision of Professor Adolph Knopf and this opportunity is taken to express the deep gratitude which the writer feels for the unfailing interest taken by Professor Knopf in this work. In addition, the writer wishes to thank Professor Knopf for a thorough inculcation of the methods of scientific research.

The writer is also greatly indebted to Professor C. R. Longwell for his sympathetic supervision and for the great amount of time and effort which he kindly spent in his guidance of the writer's work.

To Professors C. O. Dunbar, R. F. Flint, W. E. Ford and to Doctor M. R. Thorpe the writer wishes to express thanks for their kind suggestions, helpful criticism and the general assistance which they

never begrudged him. The writer also wants to thank Professors A. M. Bateman, Ellsworth Huntington, R. S. Lull, C. H. Warren and Doctor G. R. Wieland for many favors received during the course of the present investigation.

Financial assistance received from Yale University in the form of two Dana fellowships greatly helped in bringing this work to completion. Finally, the writer wishes to thank Mr. Percy Morris of the Peabody Museum staff for helping with the photographic work.

Throughout the incubation and typing periods of the manuscript the writer was helped and inspired at every turn by his wife, Josephine Doyle Krynine.

During a later revision and preparation of the manuscript for publication, in 1945, considerable assistance was received from Mrs. R. O. Hotton and Mrs. V. S. Westlake.

It would not be proper for the writer not to mention the deep influence of the late Professor Joseph Barrell upon this present work. Indeed, any student of continental sedimentation must be strongly impressed by the pioneering work of Barrell.

Barrell introduced order and sensible system into the study of continental sedimentation. He showed how to replace hasty generalizations by critical analysis and the presentation of pertinent proof based on authenticated facts. To get all that can be gotten out of Barrell is not easy, for many of his most significant statements are extremely concise. No wonder that Barrell has been misinterpreted. His discussion of the effect of topography on sedimentation, specifically restricted to mature topography, has been misapplied to cover all phases of the geomorphic cycle. His concept of seasonal precipitation has been transformed into a dogma for limited rainfall. His brilliant exposition of a chemically non-reducing environment on a slope of deposition has remained buried and but little known in the depths of his paper on the Mauch Chunk shale.

It is the writer's hope that in his attempt to solve the problem of the Triassic of Connecticut, he has been able to follow faithfully in Barrell's footsteps and employ the methods used by him: a critical dissection of a problem into its component elements; a careful study of all the data and especially of such parts as appear to be conflicting; a very critical review of environments which could have harbored the process responsible for a given sedimentary feature; and finally, a presentation of conclusions on the basis of the available authentic facts even if such conclusions are at variance with previously accepted theories.

Geography, Topography, Drainage and Climate

The Triassic basin of the Connecticut Valley is a member of a series of essentially similar basins distributed along the Atlantic coast

of North America from Nova Scotia to South Carolina (Fig. 1). The total length of the Triassic belt reaches 1,200 miles; its maximum width (in North Carolina) approaches 100 miles. There is a striking resemblance between the different areas in respect to lithology and structure.

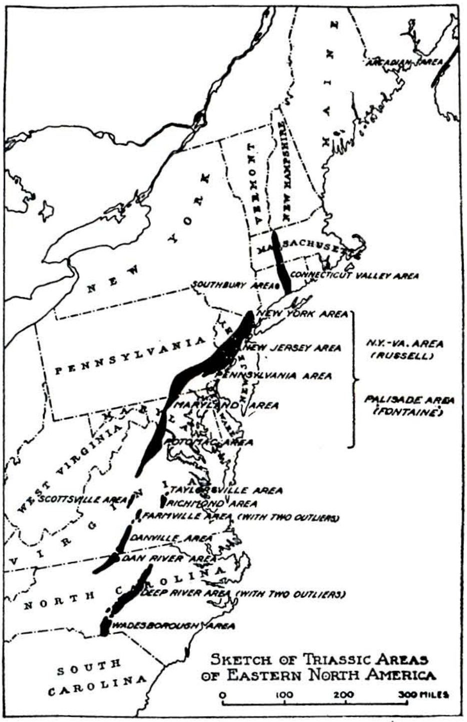

Figure 1. Index map of the Triassic belt of eastern North America (after I. C. Russell and J. K. Roberts).

The area covered by Triassic sediments in the Connecticut Valley extends from New Haven Harbor almost to the boundary line between Massachusetts and Vermont (Fig. 2). A minor Triassic basin the Pomperaug basin, is disposed 12 miles west of the main Triassic area. The Connecticut Valley area is 108 miles long and from 3 to 22 miles in width, 16 to 18 miles being the average. The distance between the western boundary of the Pomperaug basin and the eastern boundary of the main area is 32 miles. The surface of the Connecticut Valley area is estimated at 1,311 square miles, that of the Pomperaug area at 14 square miles.

The Connecticut Valley forms a long topographic depression running north and south and bordered on both sides by highlands known among Connecticut geologists as the Eastern and Western Highlands. The region of the valley lowland is underlain by weak

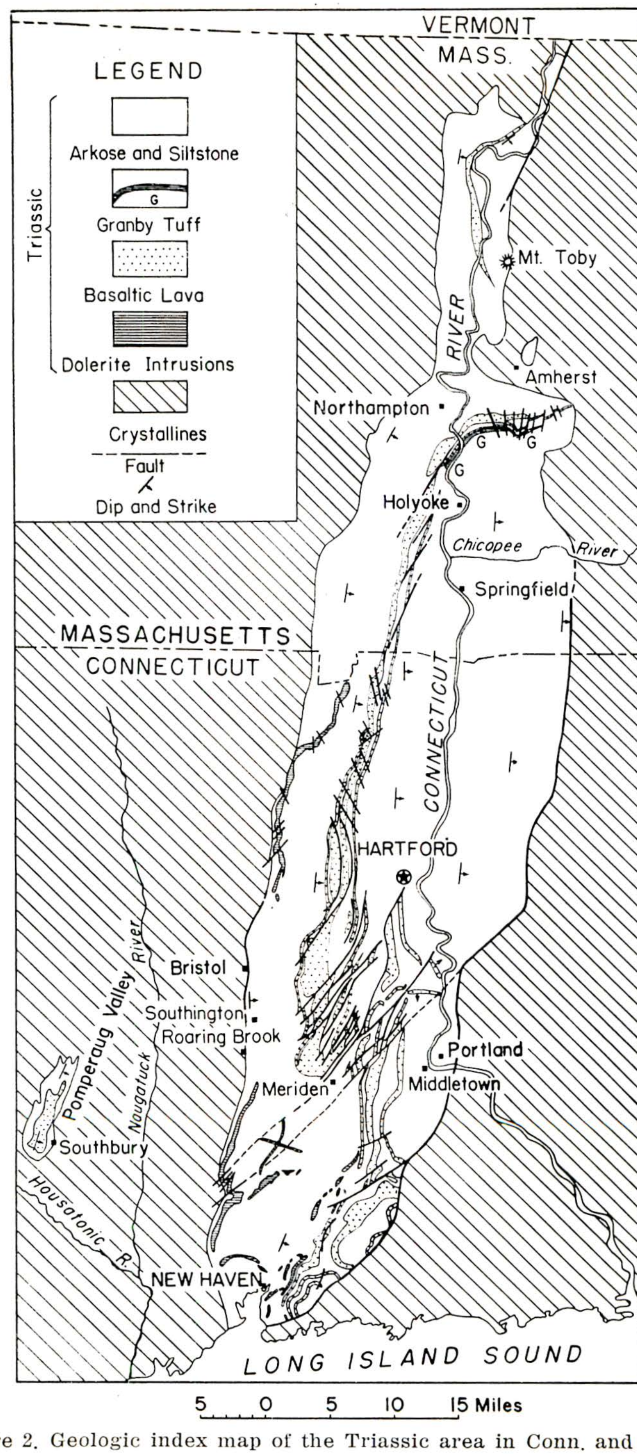

Figure 2. Geologic index map of the Triassic area in Conn. and Mass. (Modified after C. R. Longwell)

Triassic sediments, the two highlands are formed by more resistant crystalline igneous and metamorphic rocks. Resistant ridges of trap rock rise boldly several hundred feet from the floor of the valley. The valley is thickly settled, roads are abundant and outcrops fairly numerous and easily accessible. On account of the weakness of the Triassic sediments, most outcrops are extremely poor, small in extent and badly weathered. Good and fresh exposures can be obtained best from quarries, but the latter, unfortunately, are located within a limited stratigraphic range. New road cuts, if visited shortly after their construction, provide excellent exposures, but they do not stay unweathered for long.

The different lithologic members of the Triassic section are unequal in their resistance to erosion: siliceous siltstones are most resistant and form minor ridges; arkoses are next; and clayey sandstones and shales are weakest and provide no topographic expression whatever.

The Connecticut River drains the northern and central parts of the valley, to the latitude of Middletown, where it leaves the valley through a narrow gorge carved from rocks of the Eastern Highland. The southern portion of the valley is drained by several small streams, the Quinnipiac River being the most important.

The climate of the region is humid temperate. In the southern part, at New Haven, the mean annual temperature is 49.9°F. (29.2° F. in January, 71.9°F. in July) and the rainfall averages 45.77 inches per year, uniformly distributed. In the northern portion, at Amherst, the mean annual temperature is 46.8°F. (23.8°F. in January, 71.0°F. in July) and the precipitation averages 44.17 inches, also uniformly distributed.

For a complete and detailed account of the topography, drainage and broad relationships of the region, the reader is referred to the works of Davis (1898), Longwell (1932) and Flint (1930).

Previous Work Done on the Region

A considerable literature (over 250 titles) has been published on the Triassic rocks of the Connecticut Valley. In addition, well over 1,200 papers deal with the Triassic of eastern North America and many of them bear some relation to the Triassic of Connecticut.

Most of the early papers are of historical interest only. They have been briefly annotated in Gregory's "Bibliography of Connecticut geology" (1907). Practically all our present knowledge of the Connecticut Valley Triassic has been the result of the work of a few outstanding investigators: Silliman, Percival, Hitchcock, Dana, Russell, Davis and Hobbs in the 19th century; Barrell, Lull, Longwell and Thorpe in recent years.

Silliman. The sandstones and traps of the Connecticut Valley were first described by Benjamin Silliman in a series of papers published between 1806 and 1837. Silliman recognized the intrusive origin of the trap and as early as 1830 emphasized the importance of detailed study of the contacts between trap and sandstone. These principles later on were used to good advantage by Davis in solving the structural relations of the area.

Percival and Hitchcock. An outstanding contribution to the geology of Connecticut was made by Percival (1842). The keenness and accuracy of his observations have hardly been surpassed by later observers. Even now, Percival's descriptions are the only ones available for certain portions of the State. Percival assigned the Connecticut red beds to the "secondary" (New Red) sandstone, formed in local depositional areas and "apparently independent of any more extensive formation" (p. 430). He apparently believed that all trap rocks were dikes. As a whole, his approach is descriptive and he attempts but little to interpret the facts which he observed so well. Percival's work is one of the greatest classics of field geology.

Percival's work in Connecticut was contemporaneous with Hitchcock's studies in Massachusetts (1835, 1841). Hitchcock was especially interested in the paleontological aspects of the problem and in his "Ichnology of New England" (1858) he made the study of fossil tracks a full-fledged branch of paleontology.

Dana and Russell. The Triassic rocks of southern Connecticut were studied for almost fifty years (1845-1892) by J. D. Dana. In the later part of this period I. C. Russell described the Newark sediments of New Jersey and synthesized the current knowledge of eastern North America.

Russell arrived at the conclusion (1878, 1880) that the different Triassic areas were formerly much larger in extent and probably are the remnants of one single, large depositional area, subsequently dissected (the so-called "broad terrane hypothesis," 1892).

Following in the footsteps of Lyell, who, as early as 1842, had compared the Connecticut Valley red beds with the sediments of the Bay of Fundy, Russell (1879) believed in an estuarine origin of the Triassic formation. In the matter of Triassic climate, Russell thought that these red beds were deposited in a "warm humid climate" (1892, pp. 52-53 and 1889, p. 46) from "debris of lands that had been long exposed to the action of a warm, moist atmosphere."

Many of Russell's views were not accepted by Dana. On the basis of his experience in southern Connecticut, Dana objected (1879 and 1883) to the broad terrane hypothesis because the area in question had too prodigious an extent for one single estuary and also because the frequent presence of coarse conglomerates near the borders indicated individual basins of deposition. Dana accepted to some extent the estuarine theory of origin for the Triassic, but in his later papers his

description of the processes involved almost suggests ordinary fluvial, rather than typically estuarine conditions; he said (1883, p. 384): "Triassic deposits...in the Connecticut Valley correspond...to those of fluvial and estuarine origin." Isolated pebbles and cobbles ("up to 6 inches in diameter") in finer sediments were interpreted by Dana as good evidence for ice floes and the fanglomerates of the eastern border were considered to be stratified drift. This led Dana to assume a glacial climate for the latter part of the Newark epoch.

Dana rather vigorously championed the theory of intrusive origin of the trap. This led him into a prolonged controversy with Davis, who maintained that most of the trap bodies were extrusive (flows) rather than intrusive (sills).

Davis and Hobbs. A detailed survey of the Triassic rocks of Connecticut was carried on for a period of 20 years (1879-1898) by W. M. Davis. In addition to almost a score of progress reports, the final results were presented in 1898 in "The Triassic formation of Connecticut," which formed part of the 18th Annual Report of the U. S. Geological Survey. This classic monograph has remained until today the fundamental work on the Connecticut Triassic.

Davis proved the extrusive character of most of the trap bodies. Using the three lava flows as key beds, he divided the Triassic strata into four main horizons. Unfortunately, he retained Percival's somewhat unwieldy terminology (anterior, main, posterior trap, etc.). Then, with the aid of the same lava flows and of two horizons of fossiliferous black shales, he solved the complicated structure of the Connecticut Triassic basin and proved it to be a monocline, bordered by a large marginal fault on the east and extensively broken up by block faulting.

Davis also showed that Triassic sedimentation began on what he described as a pre-Triassic peneplane and that the processes at work were essentially those of normal continental deposition. The broad terrane hypothesis was rejected (p. 191); "no great original extension of the formation is necessary to the east or west of its present limits". However, the possibility of a small extension of the Triassic beds westwards, possibly as far as the Pomperaug basin, was not denied.

To account for the great thickness of the Triassic strata (estimated by him at over 10,000 feet) Davis suggested the continued sinking either of a trough produced by downwarping, or of a block bounded by faults. He favored downfolding rather than a graben, the latter being the explanation advanced by Emerson (1898).

In the matter of climate Davis adopted Russell's views (p. 39): ". . . the prevailing red color of the Triassic strata is best explained as a result of slow and deep weathering in a mild climate". He deemed that the conglomerates were not of glacial origin.

Finally Davis gave a history of the post-Triassic tilting, the Cretaceous peneplanation and the subsequent elevation and erosion which, modified by glacial action, produced the present topography.

Hobbs published in 1901 a study of the Triassic rocks of the Pomperaug valley. This paper was inspired by Davis's work, but, dealing with a small area, was much more detailed. In addition to stratigraphic and petrographic descriptions, Hobbs placed particular emphasis on structure. He attempted to show that the Pomperaug basin had been fractured into several hundred fault blocks which he rather ingeniously reconstructed. His conclusion was that such an extremely complicated structure was to be explained best by assuming a recurrent (double) compressive movement in an almost east-west (N 80° W) direction. Hobbs' structural interpretations are open to some doubt and have been questioned.

Barrell and Lull. Barrell gave much attention to the relation between climate and terrestrial deposits (1908). He arrived at the conclusion that the Triassic red beds were formed under semi-arid conditions, a view which has influenced students for many years. Later (1915) Barrell presented a brilliant picture of "Central Connecticut in the geologic past" in which he demonstrated that Triassic sedimentation was controlled by the depression of a wedge-shaped block along a great normal fault which formed the eastern border of the basin. He also carefully described the post-Triassic geologic history of the region.

Lull wrote a classic study on the "Triassic life of the Connecticut Valley" (1915). In addition to this monograph he published a series of other fundamental works on Triassic paleontology and the interpretation of fossil tracks. In the matter of climate, Lull relied mostly on sedimentary evidence as interpreted by Barrell.

Emerson, Gregory, Rice, Foye. Surveys of different parts of the Connecticut Valley Triassic were made by Emerson in Massachusetts (1898, 1915) and by Rice and Foye in central Connecticut, mostly around Middletown (1927). Rice and Gregory cooperated on the "Manual of the geology of Connecticut" (1906). All these papers are on the whole purely descriptive.

Longwell and Thorpe. To Longwell we are indebted for a systematic study of the complicated structural relationship of the Triassic area (1922, 1928) and for a modern description of the stratigraphic sequence (1933). He also showed (1922) the existence of Triassic alluvial fans extending westwards from the Great Fault. Finally, in rewriting and considerably enlarging J. D. Dana's guide to the geology of New Haven (1932), Longwell made available a manual of the most important field facts to be seen in the Triassic belt of Connecticut.

Thorpe, in addition to his paleontological work on the Triassic fauna, increased our knowledge (1927) of the stratigraphy of the upper part of the Triassic section.

Russell and Bain. W. L. Russell published (1922) an exhaustive study of the Great Fault. He confirmed Barrell's ideas of the recurrent growth of this fault during Triassic times.

G. W. Bain (1932) described the northern area of the Triassic basin in Massachusetts and especially the Triassic-crystalline contact at Mt. Toby. He advanced the idea that overthrusting rather than normal faulting had taken place along the eastern border of the Triassic area. He also suggested that the Triassic trough was bordered on the east by high, glaciated, maturely dissected mountains. These ideas have not been widely accepted.

Statement of the Problem

When the present investigation was begun the following facts had been established by previous students of the Connecticut Triassic:

1. A general description of the stratigraphy based on field relations had been made by Davis (1898) and refined by Thorpe (1928) and Longwell (1933).

2. The Newark sedimentary rocks of the Connecticut Valley were shown to be probably of Upper Triassic age. These rocks consist of arkoses, conglomerates, fanglomerates, shales and subordinate limestones. Most of the sediments are red in color. Their total thickness apparently reaches 14,000 feet. They are interbedded with three basaltic lava flows and are intruded by innumerable doleritic sills and dikes, the largest sill (400 feet thick) occurring near the base of the Triassic section.

3. The sediments are of non-marine origin.

4. The Triassic basin of deposition was bordered on the east by a major fault. Fanglomerates are present along this fault and alluvial fans appear to radiate westward from the fault (Longwell, 1923).

The following points were doubtful or controversial:

1. Whether the climate prevailing during the Newark epoch was semi-arid (Barrell), humid (Raymond), or possibly neither one of these.

2. Whether the relief of the highland east of the Great Fault was low, moderate, or high (Bain).

3. Whether most of the sedimentary detritus was derived from the Eastern Highland (Barrell) or equally from both sides of the basin (Roberts). This implies a reconstruction of the Triassic drainage pattern.

4. Whether the Great Fault is a normal fault (Barrell, Longwell) or a reverse overthrust (Bain).

Finally no data were available on the following subjects:

1. A detailed knowledge of the petrography and mineralogy of the Triassic sedimentary rocks.

2. An understanding of the interrelationships between the members of the major sedimentary units (lensing, facies, overlap, etc.).

The present investigation was undertaken to obtain the necessary petrographic, mineralogic and field evidence and on the basis of this information to attempt to solve the following problems:

1. Probable climate of the Newark epoch.

2. Character and peculiarities of Triassic sedimentation.

3. Location, shape and extent of the source area whence the sedimentary detritus originated.

4. Original shape and extent of the Triassic basin of deposition.

5. Primary structure of the same basin.

6. Character and extent of subsequent deformation.

7. Paleogeography of eastern North America during Newark time.

Method of Work

In addition to the usual field work (mapping and especially thorough examination of the better exposures) and the study of 125 thin sections, an investigation of the heavy minerals was made according to the usual technique described in Milner and other works on sedimentary petrography. It was found that in dealing with numerical values, an accuracy greater than one per cent was not justified, in view of the great variability of the continental deposits under study. Each sediment usually was a problem in itself and certain modifications of technique were always necessary.

Heavy minerals were highly valuable for purposes of correlation and stratigraphic work in general, but thin sections proved to be essential when attempting to reconstruct the genesis and history of a rock. The results are based fundamentally on thin-section work.

A typical work schedule, in addition to megascopic study and investigation of the thin section, consisted of:

1. Crushing (not grinding) of a sample. A quantity as small as 20 grams was found to yield frequently 10,000 or more heavy mineral grains. The amount crushed depends upon the kind of work contemplated (mechanical analysis requires more) and the coarseness of the rock. The following amounts yielded as a rule enormous crops of heavy minerals: conglomerates and coarse arkoses — 100 to 150 grams; medium-grained sandstones—50 to 100 grams; fine sandstones, siltstones and shales — 20 to 40 grams.

2. Cleaning of the crushed sample. If no calcite or ferric oxide were present, ordinary water was sufficient. Otherwise, cold or boiling dilute HCl (20 per cent) was used. Much of the troublesome red ferric oxide is contained in the finest clayey material and can be removed by simple repeated decantation in water prior to boiling with acid. The addition to the acid of a very small amount of stannous chloride greatly expedites the removing of the ferric oxide coating on mineral grains.

3. If a mechanical analysis was required, then first the clay content was determined by settling the sample through a 15 cm. water column. This resulted in the elimination of particles finer than 10 microns which were decanted after 20 minutes. After drying, the sample was cleaned with acid and the soluble portion determined. Frequently these two operations could be combined if a study of the thin section and the lack of calcareous material indicated that the ferric oxide was in the form of ferruginous clay. The dried insoluble residue was run through a mechanically operated set of sieves and the following fractions were separated (after Wentworth's scale):

Gravel	caught on	9 mesh	(1.985 mm.)
Very coarse sand	" "	14 mesh	(1.068 ")
Coarse sand	" "	32 mesh	(0.495 ")
Medium sand	" "	60 mesh	(0.245 ")
Fine sand	" "	100 mesh	(0.147 ")
Very fine sand	" "	200 mesh	(0.074 ")
Silt	passes	200 mesh	(0.074 ")
Clay	separated by elutriation.		

To bring out the differences between petrographic end members (see p. 73) Table 4A shows under one heading the ratios of cement and clays to entire rock and under another the mechanical analysis of the sandy and silty fractions only (minus clay). In all other tables and graphs, the combined results of acid treatment and mechanical analysis including clay have been recomputed on a 100 per cent basis for the original rock.

4. Heavy minerals were obtained through bromoform separation from the mixed sandy fractions which passed the 60 mesh (under 0.25 mm.), and when necessary another crop was obtained from the medium sand fraction (0.5-0.25 mm.). All the correlation work was done on the basis of the heavy minerals derived from the fine, very fine and silt fractions (0.245-0.074 mm.). Sometimes the finer fractions were differentiated and subjected to a separate bromoform treatment. It was found that the proportion of heavy minerals to the total weight of the sample was a function of the general coarseness of the sample: the finer the sand, the more abundant the heavy minerals. Hence, the ratio of the heavy minerals to the total sample cannot be used as a criterion for correlation in continental clastics, and especially in fluvial sediments, where coarse arkoses and fine-grained siltstones may be intimately interbedded. These arkoses and siltstones may be identical in origin as seen from their heavy-mineral assemblages and

mineral frequencies, but they will possess vastly different ratios of heavy minerals to the total sample.

Magnetic concentration was used when required and the heavy minerals were permanently mounted in Canada balsam (n = 1.54) or in piperine (n = 1.68) when investigation of minerals with very high refractive indices was desired. Frequencies were determined by counting (300 to 600 grains). No significant improvement in accuracy was observed when the count was raised from 350 to 1,000 grains. Additional auxiliary methods required in some specifically difficult instances are treated in the section on petrography.

CHAPTER II

MINERALOGY

The Main Rock-forming Minerals

Quartz

The quartz grains are generally very angular. Perfectly pitted and rounded grains, apparently derived from an older, pre-Triassic sedimentary cover, have been observed in the lowermost Triassic beds at Dawson Lake. Otherwise the angularity of the quartz is extreme.

The grains vary greatly in size, the larger ones being somewhat better rounded. The quartz is colorless, milky-white, or smoky gray.

Under the microscope much of the quartz shows undulose extinction of varying degrees of intensity. Some grains show powerful undulose extinction and their strain-shadows present such a crenulated or serrated aspect as to give to the grain an almost facetted appearance. Such grains of extreme metamorphic origin are especially common in the lower part of the section. Other grains (derived from granitic bodies) show only the weakest of strain-shadows.

All quartz grains contain inclusions, usually in the form of elongated subparallel rows and chains of black specks, microlites and bubble cavities. Inclusions in the shape of larger crystals of biotite, zircon, titanite, tourmaline and rutile are also common at some places. Thus all the types of inclusions described by Cayeux, Mackie and Gilligan are present and a complex igneous and metamorphic origin is indicated as a result. Graphic and microperthitic intergrowth with feldspar is common in certain localities.

Overgrowths of secondary silica in the shape of sharp terminations and pyramidal faces on detrital quartz grains are very rare. They have been observed in less than 15 per cent of the examined samples. Almost three-fourths of these secondary quartz developments are the result of contact and hydrothermal action and the balance is restricted to the lacustrine beds of the Meriden formation.

These authigenic occurrences are described on some detail in the chapter on Petrography.

Feldspar And Its Weathering

Although the feldspar grains are generally angular or sub-angular, they show nevertheless a much greater rounding than the quartz. At some places even well-rounded feldspar grains are found. Some of the angular grains were formed by the refracturing of rounded grains along cleavage planes. A quantitative treatment of this rounding is given in Chapter IV (Petrography).

The feldspar is either pink (mostly microcline) or colorless (microcline or plagioclase).

The microcline possesses at least three apparently different grid-twinning patterns:

1. Rectangular pattern
2. Diagonal straight pattern
3. Diagonal wavy pattern

Each of these patterns may be fine or thick, thus giving rise to at least six possible varieties. Microperthitic intergrowths and inclusions in the shape of quartz blebs are common. Orthoclase is rather rare.

Plagioclase is mostly albite (An 2-An 10), less commonly sodic oligoclase (An 14) and very rarely some of the more calcic types.

Microcline predominates over all other types of feldspar. This predominance is due, however, not only to its superior resistance to decay, but also to the much greater relative abundance of microcline among the crystalline rocks of the source area.

As a whole the feldspar is fresh, but all degrees of weathering and alteration can be found. Most of this alteration is primary (pre-depositional), some is post-depositional but pre-diagenetic, some is diagenetic-secondary (sericitization) and some is recent, due to the weathering of outcrops. Replacement by calcium carbonate is widespread. Although microcline is less susceptible to sub-aerial decay than orthoclase and the plagioclases, it does not seem to resist hydrothermal or at least underground replacement by calcite any better than plagioclase; on the contrary, it appears to be a trifle more susceptible. The differential weathering of feldspars is discussed in some detail in the chapters on Petrography and Climate.

Micas

Micas are especially abundant in the finer-grained rocks. They form from one-half to six per cent of the sandstones and up to 50 per cent or more of some shales. They occur generally as relatively large flakes from two to fifty times larger than the average grain size of the other constituents. Mica-flakes up to 1 cm. and more in diameter are common at all levels of the Triassic section.

Muscovite is infinitely more conspicuous than biotite in outcrops and hand specimens, but in thin section, it is seen that biotite forms as much as one-third of the total mica content. The micas, especially biotite, carry a large number of inclusions in the form of small crystals of zircon, surrounded by pleochroic halos and, less commonly, magnetite, tourmaline and rutile. The perfect idiomorphism and lack of wear of many zircon prisms may be due partly to their transportation as protected inclusions within mica flakes.

The biotite, like the feldspar, shows all degree of alteration from perfectly fresh flakes to deeply decayed and oxidized ones. Various degrees of alteration may be seen within the area of one single thin section.

Clay Minerals: Kaolin, Gibbsite and Hematitic Clay

All specimens contain some clayey matter which generally is made up of kaolin, although in some specimens there may be considerable sericite and illite. Furthermore, a certain portion of the clay fraction is not kaolin, but one of the members of the bauxitic group, presumably gibbsite.[1]

Much of the clay is stained red by very fine-grained hematite. Pure hematite is rare outside of coatings on quartz or feldspar grains.

The amount of hematite in the clay varies considerably. Two chemical analyses showed that in a very bright red, typical Redstone (specimen 36) 9.01 per cent of Fe_2O_3 is present, whereas a moderately red arkose (specimen 13 from the Fair Haven quarry) contains 2.39 per cent of Fe_2O_3.[2]

These figures indicate that within these specimens the amount of hematite present in the "hematitic clay" is around 25 per cent of the clay total.

Calcite

Calcite is present in approximately 35 per cent of the examined specimens, but is abundant in not more than 10 per cent of them. With the exception of the algal (?) limestone beds of the Meriden formation and some highly calcareous lacustrine shales, also from the Meriden beds, calcite is generally secondary, diagenetic, or more probably, of post-diagenetic origin and its occurrence in practically every case is related to the immediate vicinity of some major fault that provided a large circulation of solutions, possibly of late- or post-magmatic origin, related to the trap bodies.

Mineral Aggregates and Rock Fragments

A certain portion of each specimen, especially in the coarser sizes, consists of rock fragments and mineral aggregates. Pebbles of granite, graphic granite, granite pegmatite, chlorite schist, various types of mica schist, quartzitic schists and a few gneisses and numerous vein quartz aggregates are present throughout the section. The metamorphic material is especially abundant near the bottom of the Newark and again, very locally, in certain portions near the top.

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[1] Semiquantitative X-ray tests were run in December 1945 by Dr. T. F. Bates of the Pennsylvania State College on the fine fractions of samples 13 and 36. Both samples proved to contain gibbsite in amounts estimated at between 5 and 20 per cent of the clayey matter found in each sample.

[2] Mrs. R. O. Hotton of The Pennsylvania State College, analyst.

The Accessory Heavy Minerals

Detrital Minerals

Apatite. This mineral has been observed only rarely. This lack may have been partly due to the cleaning of the iron-stained sands with hot HCl, a process during which apatite may be destroyed.

Augite. A locally abundant mineral occurring as irregular cleavage fragments showing a vivid green color and an extinction angle between 38° and 50° (Plate IV-A).

Chlorite. A common but not abundant constituent, mostly in chlorite-schist pebbles.

Epidote. Occurs as bright colored, vivid green idiomorphic crystals, prism fragments, or rarely as rounded grains. Usually transparent. Inclusions (bubbles and specks) are uncommon. Pleochroism is weak. Many grains show a remarkably strong dispersion: P V. This is a characteristic species of the southern Connecticut facies of the Triassic section (Plate I-A).

Fluorite. Occurs as colorless, usually triangular, cleavage flakes and fragments.

Garnet. This is the most common and one of the most important minerals of the Connecticut Triassic. It occurs usually as broken fragments of larger crystals and rarely as small dodecahedrons. The size is variable, with grains up to 0.75 and 1 mm, being present.

There are two main color varieties — pink and colorless. Deep red grains are very rare. The ratio of pink to colorless garnet is important in the correlation of stratigraphic horizons and geographic facies.

The surface of the garnet is frequently etched, pitted, grooved and puckered. Refraction phenomena at places give to such pitted surfaces a bluish tinge (Plate IIa-A) and at others make it appear almost black.

A few of the garnets are altered and corroded as the result of intrastratal changes, particularly close to the lava sheets (Plate IIa-B). Inclusions are common but not abundant. They consist mostly of bubbles or of some unoriented black specks.

The skeletal or drusy development mentioned by Gilligan (1919, p. 265) is a feature of many garnet grains. Some grains have a true skeletal appearance.

Hornblende. A rare constituent, present mostly near the base of the section. The color is yellow-green to bluish-green, the extinction usually low (8° to 12°). Fibrous, actinolite-like varieties are very rare.

Indicolite. This blue variety of tourmaline is one of the most important Triassic minerals. It always occurs as angular fragments of larger, broken-up crystals and never as idiomorphic prisms. Some of these fragments exceed 0.5 mm. in diameter. It is always clear and limpid, without any inclusions. The pleochroism is very strong, the pleochroic formula being:

X. — Pale to deep mauve
Z. — Pale to deep indigo blue

The extremely marked pleochroism apparently makes this an abnormal variety for, according to Milner (p. 248): ". . . blue tourmaline (Indicolite) is invariably weak in this respect."

The indicolite is of great stratigraphic significance, being an excellent horizon and locality marker (Plate IV-A and B).

Kyanite. Occurs as irregular or rectangular cleavage fragments (Plate I-A) colorless or grayish in color. Rounded pieces are rare.

Monazite. Occurs mostly as rounded or equant grains (Plate I-B). Some, however, are subangular. The color varies from almost colorless to the usual light greenish yellow or yellowish green of various degrees of brightness. Dark borders are typical. The surface may be scratched and pitted. Inclusions are rare, consisting mostly of gas filled cavities and dark dust. Few of the grains give good interference figures, but the positive sign and a small optic angle can be determined in any residue where confusion with epidote is possible.

Rutile. This mineral is at some places very abundant and it occurs in a variety of forms and colors: foxy-red, amber-yellow, and very rarely, purple. Fragments of prisms, or whole squat (1 x 1) to very slender (1 x 8) prisms, frequently exhibiting very good idiomorphism, are the usual habit. These prisms may have striated surfaces (Plate II-C). Very rarely they are etched and reduced almost to a skeletal appearance. Twinning (Plate II-B) is common, geniculated twins being the variety usually present.

Sillimanite. Rarely found as long slender needles, or needle-aggregates.

Staurolite. Occurs in a variety of colors: from very pale yellow to deep golden yellow, with weak or strong pleochroism. Present as irregular, angular or subangular grains, some of which contain numerous dark inclusions. The surface may be etched (Plate III-A).

Titanite. May be very abundant locally. Varies in shape, from well developed, typical rhombs and prisms, through partly idiomorphic fragments (Plate III-B) to almost rounded grains. The color is grayish-brown. A surficial film renders many grains almost opaque. At certain places some of the titanite is imprisoned as inclusions in large quartz grains which thus prevent a good bromoform separation.

Tourmaline. Ubiquitous at all levels of the section. Occurs as three distinct color varieties which do not grade into each other.

1. Brown tourmaline with the following pleochroic formula:

X. — Colorless, pale yellow, sepia
Z. — Pale yellow, sepia brown, black

Occurs almost exclusively as well developed small idiomorphic prismatic grains, rarely as broken, basal or random sections. Size varies from 0.1 to 0.5 mm. The following types of inclusions were observed.

a. Small irregular cavities and black dust.
b. Clouds of minute black dust, apparently carbonaceous matter.
c. Large rounded reddish or greenish bubbles and fluid cavities.
d. Small, equant or prismatic crystals of rutile and zircon.
e. Slender needles and acicular crystals too small to be successfully identified.

The color and type of inclusions have a definite bearing on the provenance of the mineral. It has been found that the tourmaline of the Connecticut schistose rocks of low metamorphic rank (phyllites, chlorite-schists and some mica-schists) is generally very pale colored (X — colorless, Z — pale yellow) and contains an extremely abundant amount of inclusions of Type b which give to it a cloudy, almost opaque appearance.

2. Pink tourmaline, with the following pleochroic formula:

X.—Pink, reddish, chestnut brown, reddish brown
Z.—Reddish black with greenish fringe across borders

Occurs usually as broken fragments of larger prismatic crystals. The small, idiomorphic prisms characteristic of the brown variety are almost never present. Inclusions as a whole are also rare,

3. Green tourmaline, with the following pleochroic formula:

X.—Pale green, very pale pinkish green
Z.—Deep green, bluish green

Occurs mostly as angular basal or prismatic fragments. Idiomorphic prismatic crystals are rare, but less so than in the case of pink tourmaline.

In addition, purple tourmaline, a very rare variety, is present only in the sediments of the Pomperaug basin.

Blue tourmaline belongs to the deep blue indicolite variety and on the basis of its distinctive morphology and great stratigraphic significance deserves to be rated as an individual species (see indicolite).

Xenotime. This mineral is listed only tentatively. Its presence is suspected from the fact that certain of the zircon-like minerals seem to possess a relief apparently below normal (they appear blue in piperine). Also some of them are covered with a thin semi-opaque buff film, which may be the cerium oxidized film often present on the surface of xenotime. The fact that normal zircons possess inclusions of monazite — a fact which makes them cerium-bearing — does not allow the use of spectrographic or microchemical methods to separate positively xenotime from zircon.

Zircon. This interesting and abundant mineral occurs in a number of types. Two main color varieties can be distinguished: colorless (often water-clear), and deep-colored bluish, smoky, or pinkish blue.

If British practice is followed and the zircons are subdivided on the basis of their inclusions, form, zoning and idiomorphism, then as many as twelve or fifteen types or subvarieties of Triassic zircon can be distinguished. However, inasmuch as all these types come from a small petrographic province, some of them are found to grade into each other. Hence in addition to the clear-cut twelve or fifteen end types, an even longer series of intermediate subtypes is also present. This makes the establishment of a definite zircon classification difficult, although far from impossible.

The zircons are usually idiomorphic prisms bordered by pyramids. The terminations may be sharp or appear to be almost rounded due to the multiplication of vicinal faces (Plates III-A and II-B). True rounding is rare. Capped crystals have been observed twice.

Inclusions may be entirely absent or on the contrary extremely abundant. These inclusions consist of:

1. Bubbles, often very large and irregularly shaped.
2. Slender rod-like non-identifiable crystals, often oriented after the outlines of the prism.
3. Chains and rows of black dots, dust and small cavities, typically oriented across zircon prisms although they may occur at an angle to it or be bunched together, or rarely even parallel to the C-axis.
4. Recognizable crystals and microlites of zircon, rutile and monazite.

Many crystals are perfectly zoned (Plate III-A).

Some zircon grains show irregular and pitted surfaces, the origin of which is somewhat obscure. It may have been due to corrosion, or possibly to breaking upon impact of fractions of the outer shells in the zoned varieties (Plate IIa-C and IIa-D).

Zoisite. A rare colorless mineral, showing typical ultra-blue birefringence. Occurs mostly together with epidote.

Iron Ores

Magnetite, ilmenite, leucoxene. Members of this series are universally present, ilmenite being the most abundant.

Hematite and limonite. Hematite is the most characteristic Triassic constituent, being the source of most of the red color of the formation. It occurs mostly as finely disseminated pigment, but at some localities (Portland) it forms large concretions. Yellow limonite is usually the product of recent weathering of magnetite, pyrite, or ferromagnesian minerals.

Pyrite, siderite, ankerite. Pyrite is very common in the dark organic beds. It occurs as small cubes of various sizes.

Siderite and ankerite are usually associated with dolomite. They occur as well shaped brownish rhombs.

Authigenic Minerals

Anatase. Occurs either as an alteration of ilmenite and leucoxene forming small outgrowths on the latter minerals or as isolated crystals. The outgrowths on ilmenite form very small cubic aggregates. The isolated crystals occur either as cubes or as octahedrons and frequently show perfect idiomorphism and striated faces. Two main color varieties are present: yellow and blue or greenish blue. Zoning and "geometric patterning" are uncommon. Although it is found at all levels, anatase is especially abundant in the immediate vicinity of the lava flows.

Barite. This mineral occurs in two main varieties. First, as well developed crystals, usually broken into cleavage fragments. This variety is generally colorless and limpid and either does not contain any inclusions or else possesses a variable amount of inclusions, mostly small specks disposed irregularly or roughly oriented in rows diagonally to the cleavage surfaces. Second, it occurs as very irregular grains, jagged, serrated and coated with a semi-opaque or dark film. The barite is generally colorless although some grains exhibit very pale yellowish and bluish tinges (Plate V-A).

The barite is secondary and is especially abundant at places where access was easy for circulating solutions: along contact planes and fault planes. An extreme abundance of barite in a sediment generally suggests the presence of a fault in the immediate vicinity. A fault zone in Cheshire gave origin to a commercial barite deposit. Barite is also very common in the lake beds of the Meriden formation and at some places forms well shaped crystals up to 5 mm. in diameter.

Dolomite. Found rarely in the Meriden beds, either as relatively large, cleavage fragments, or as very small, perfectly developed idiomorphic rhombs closely associated with ankerite and siderite (loc. 29).

Overall Mineral Composition of the Newark Series

By combining the data of Tables 3, 4B and 4C and Figures 26 and 27, it is possible to arrive at the frequencies of occurrence of the principal minerals that form the Triassic of Connecticut. These frequencies represent the properly weighted, volumetric mineral relationships existing within the Newark, and were arrived at by multiplying the mineral composition of the principal lithological units of the Triassic by the geographic and stratigraphic distribution of these rock units throughout the Newark section.

These weighted results, surprisingly enough, are almost identical, for quartz, feldspar and the micas, with the simple mean average of all examined samples. However, as shown in Figure 3, sizable differences appear for the clay minerals and calcite between a simple arithmetical mean and a correctly weighted average.

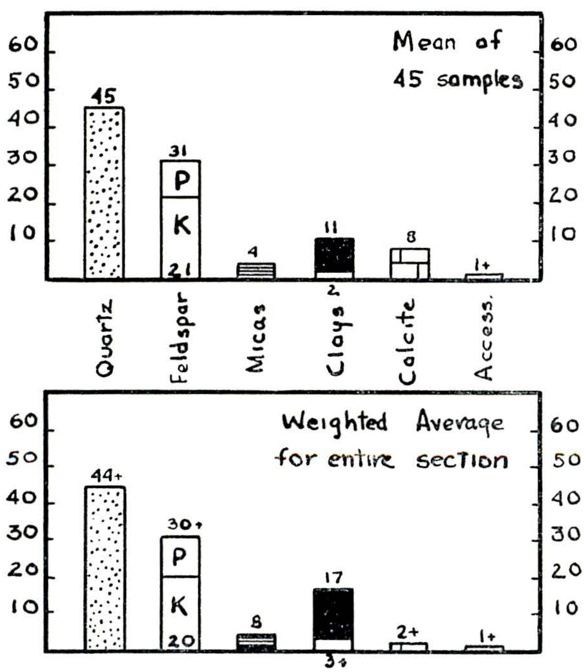


Figure 3. Overall mineral composition of the Connecticut Triassic: above, mean average of all samples; below, weighted and corrected frequencies on the basis of the relative volumetric, i.e., geographic and stratigraphic, distribution of the different rock types.

The overall average weighted mineral composition of the entire Connecticut Triassic section is as follows (possible margins of error indicated in all cases):

Quartz		44.3% (±3.0)
Feldspars		30.6% (±3.0)
Microcline	16.2% (±2.0)	
Orthoclase	4.0% (±1.0)	
Albite (Ab 94±)	6.0% (±1.0)	
Sodic oligoclase (Ab 86±)	3.4% (±1.0)	
Oligoclase (Ab 80±)	0.7% (±0.3)	
Andesine and calcic types	0.3% (±0.2)	
Micas		6.3% (±1.0)
Muscovite flakes	2.0% (±0.5)	
Biotite flakes	0.8% (±0.2)	
Chlorite flakes	1.0% (±0.2)	
Sericite-muscovite-illite paste	2.5% (±0.5)	
"Hematitic" and "white" clays (minus micas)		15.7% (±3.0)
Kaolin	11.0% (±2.0)	
Gibbsite	1.2% (±0.6)	
Hematite	3.5% (±0.5)	
Carbonates		2.5% (±0.5)
Calcite	2.3% (±0.4)	
Dolomite, siderite	0.2% (±0.1)	
Accessories		1.2% (±0.3)
Barite	0.1% (±0.05)	
Magnetite, pyrite, opaques	0.5% (±0.2)	
Non-opaque heavy minerals (anatase to zoisite)	0.6% (±0.2)	

Chapter III

STRATIGRAPHY

Introduction

History of the Problem

The Triassic rocks of the Connecticut Valley have been assigned to the Newark group, a stratigraphic unit so named by Redfield in 1856 and redefined by I. C. Russell in 1879. The term Newark group, or series, is applied to the Upper Triassic continental deposits of eastern North America. The age of these rocks has been variously estimated to range from Middle Triassic to Lower Jurassic, but the present consensus of opinion is that on the basis of their fauna and flora, the Newark series is probably of Upper Triassic age.

The Triassic rocks of the Connecticut Valley have been divided into three general "sections" by Percival (1842, p. 432):

> "The secondary rocks of the Southern basin in the large Secondary formation, present, as has already been stated, three distinct sections or ranges, namely a Western Sandstone, a Middle Shale and an Eastern Sandstone range."

Percival does not give the exact stratigraphic relationship between these "sections." He remarks that the sediments are closely related to trap ridges and he also mentions (p. 429), that "The Shale apparently has a more intimate connection with the Trap than the Sandstone." The trap ridges were named anterior, main and posterior, according to their position when approached from New Haven.

Davis (1898) proved that these trap ridges were lava flows and, using them as key horizons, divided the sedimentary rocks into four formations to which he unfortunately applied Percival's unwieldy terminology (under sandstones, anterior shales, posterior shales, upper sandstones, anterior lava, etc.). Davis's classification has been in use until now.

The present investigation shows that a division of the Triassic sediments into four units is less justified on natural grounds than Percival's original three-fold division.

Difficulties of the Problem

The Triassic sedimentary rocks of Connecticut are continental clastics, extremely variable in coarseness, sizing and composition. The variations are not only stratigraphic, but also lateral, both along and across the strike of the formations. This is due, as will be shown later, to the fact that the greater part of the section consists of coalescing alluvial fans. As a result, at any given horizon within the same

fan, the mineral composition remains the same, but the visible texture (i. e., coarseness and sizing) varies greatly from apex to periphery. Conversely, two different horizons at any given geographic point of the fan may be rather similar megascopically, i. e.. in coarseness and sizing, but may differ considerably in mineral composition.

When dealing with two major fans, or with two groups of fans, the possibility also arises that each one of these fans came from a separate source area. These source areas may have differed in their relief and in the lithology of their rock masses. Hence, the sediments which originated in these two source areas will differ not only mineralogically, but also in their degree of coarseness, the coarser material coming from the region of higher and bolder relief. Finally, if these two separate fans are deposited over the subsiding surface of a depressed trough, the possibility arises that the rate of subsidence may be unequal in both places, with resulting differences in the character of the drainage and hence the sizing, sorting and coarseness of the sediments will also be different in both places.

It has been found that all these theoretical contingencies are actually present in the Newark of Connecticut. As a result, when describing the Triassic sediments, it has been necessary to differentiate not only between stratigraphic horizons, but also between facies of the same horizon: longitudinal facies between different fans and lateral facies within the same fan, from apex to periphery.

Different facies of the same horizon may have an entirely different appearance, so different in fact as to defy correlation on a lithologic basis. Successful correlation is then possible only on the basis of mineral composition and especially the character and frequency of the heavy minerals, which have been found to be remarkably constant at the same horizon.

General Stratigraphic Section

Terminology

The Triassic rocks of southern Connecticut can be divided into three main units on the basis of their lithology. According to the localities where they are exposed best, these three formations have been named the New Haven (lower Newark), the Meriden (middle Newark), and the Portland (upper Newark).

Table 1 shows the correlation between Davis's classification and the terminology proposed in the present report. As can be seen, the New Haven arkose includes all sediments under the lower lava sheet, the Meriden formation contains the three lava sheets and all sediments in between, and the Portland arkose comprises the sedimentary rocks above the upper lava flow. Table 2 presents these three formations in further detail.

TABLE 1

CORRELATION OF CLASSIFICATION

	DAVIS 1898	KRYNINE 1936		
NEWARK GROUP	Upper sandstones	PORTLAND ARKOSE	Normal facies	Great Fault facies
	Posterior trap sheet	MERIDEN FORMATION	Upper lava flow	
	Posterior shales		Upper sedimentary division	Normal facies / Great Fault facies
	Main trap sheet		Middle lava flow	
	Anterior sandstones and shales		Lower sedimentary division	
	Anterior trap sheet		Lower lava flow	
	Under sandstones	NEW HAVEN ARKOSE	Upper division	
			Lower division	

The New Haven arkose is a relatively coarse fluvial sediment, consisting mostly of gray and pink arkoses, conglomerates, conglomeratic sandstones, medium-grained brick-red feldspathic sandstones and subordinate layers of red siltstone and shale.

The Meriden formation is a relatively fine-grained series of sediments, largely of lacustrine or swamp origin. It consists of fine-grained variegated siltstones and shales (red, black, blue, gray and green), limestones, dolomites, medium- to fine-grained white feldspathic sandstones, black and gray arkoses and subordinate layers of ordinary pink and gray arkoses. It is interlayered with three lava flows.

The Portland arkose again is much like the New Haven arkose except that near its base it contains, locally, swamp beds of the Meriden type.

These three formations form recognizable and mappable units, which, with a little practice, can be differentiated in the field without making use of the lavas as a guide. Three typical sections are graphically represented in Figure 4. The typical overall lithology of the Connecticut Triassic is shown on Table 3.

Facies

Each formation varies in habit in the different parts of the basin. Four main facies can be distinguished: Two longitudinal facies, to be referred to as the southern Connecticut and the central Connecticut facies and two lateral facies, to be called the normal and the Great Fault facies.

The lateral facies are caused by the passing of the normal sediments into fanglomerates as the Great Fault is approached. These fan-

TABLE 2

GENERAL STRATIGRAPHIC SECTION OF THE TRIASSIC

Normal Sedimentary Facies

Group	Formation	Zone / Division	Southern Connecticut	Central Connecticut	
NEWARK GROUP	PORTLAND ARKOSE	Upper zone	Generally absent (faulted out); when present, same as in central Connecticut	Medium and coarse red arkoses, with subordinate conglomerates and red shales 2,000 ft. ±	
		Lower zone		Fine- and medium-grained red arkoses and siltstones, subordinate dark shales near base 2,000 ft.±	
	MERIDEN FORMATION		Upper lava flow 50 — 150 ft.		
		Upper sedimentary division	Red fissile shales 100 ft. ±	Red siliceous sandy shales 100 — 150 ft. ±	
			Dark shales with arkose and conglomerate lenses 375 ft. ±		
			Red siltstones and fissile shales interbedded with black shales and gray feldspathic sandstones 200 ft.±	Dark shales with arkose and limestone lenses 50 — 150 ft. ±	
			Fine-grained grayish arkose with a little sandy shale 400 ft. ±	Red fissile shales, siltstones and sandy siliceous shales 600 ft. ±	
			Middle lava flow 300 — 500 ft.		
		Lower sedimentary division	Coarse pink or gray micaceous arkose with shaly lenses 600 — 800 ft.	Red fissile shales and siltstones 175 ft. ±	
			Dark shales 75 ft. ±	Dark laminated shales with limestone layers 60 ft. ±	
			Limestone 15 ft.		
			Coarse pink arkose 0-100 ft.	Maroon fissile shales 75 ft. ±	
			Lower lava flow 100 — 250 ft.		
	NEW HAVEN ARKOSE			West of Meriden	East of Meriden
		Upper division	Coarse PINK arkose with numerous conglomerate lenses forming two main horizons: near the base and near the top: subordinate layers of micaceous shaly sandstones and shales 4,000-5,500 ft.	Fine-grained (0.25-0.5 mm.) red micaceous feldspathic sandstone ("Redstone") 4,000-4,500 ft.	Coarse (1-2 mm.) pinkish gray arkose ("Lamentation)" with conglomerate layers 2,500 ft.+
		Lower division	Coarse WHITE, GRAY or MOTTLED arkose with conglomerate and subordinate micaceous shaly sandstones and shales. Many fragments of metamorphic rocks (phyllite) 2,000-3,000 ft.	Coarse grayish arkose with subordinate black shales 1,000-1,500 ft.	Not exposed
			Light gray basal conglomerate and conglomeratic arkose 200-300 ft.		

glomerates have been observed through a stratigraphic range of 6,000 feet in the Portland arkose and Meriden formation and it is permissible to infer that they are also present, although not exposed (excepting immediately below the lower lava sheet) in the New Haven arkose. The fanglomeratic Great Fault facies has a narrow geographic distribution (not over 2,000 feet), but coarse conglomerates can extend as far as one or two miles away from the fault. Most of the sediments belong to the normal facies and, unless specific mention is made to the contrary, all descriptions refer to the normal facies.

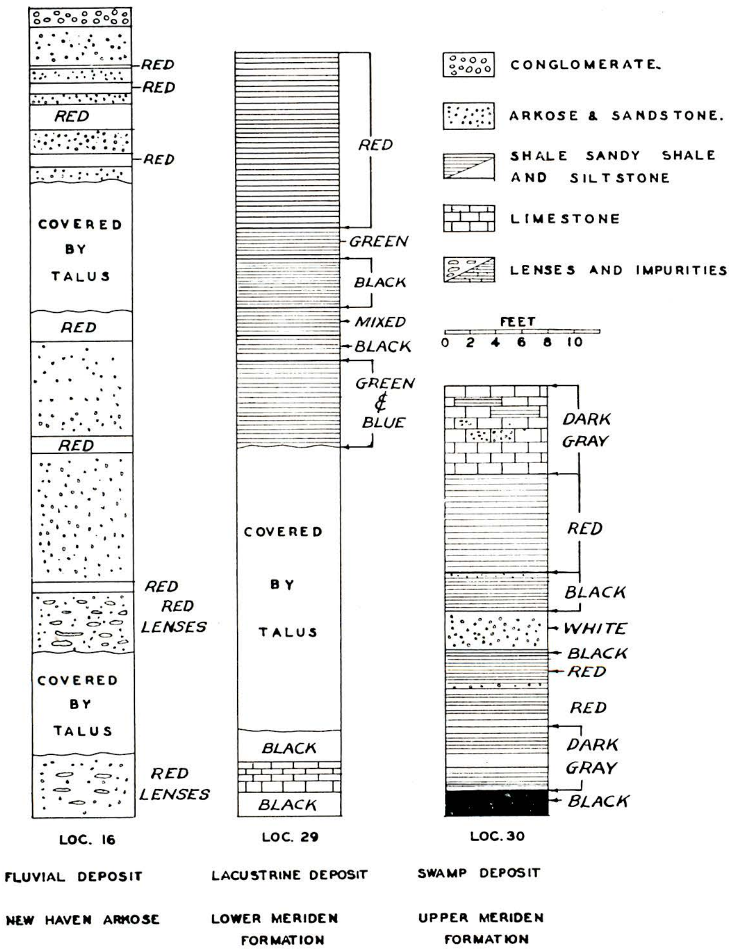


Figure 4. Three typical field sections showing differences between fluvial, lacustrine, and swamp types of deposition in the Connecticut Triassic.

TABLE 3

NORMAL SEDIMENTARY LITHOLOGY OF THE CONNECTICUT TRIASSIC

Locality	Percentage Ratio of Rock Types	Conglomerate	Sandstone	Siltstone	Shale	Limestone
General	New Haven arkose	9	76	13	2	
	Meriden formation	8	38	11	40	2
	Portland arkose	13	57	23	7	
Southern Connecticut	Lower New Haven arkose	5	67	22	6	
	Upper New Haven arkose	12	75	12	1	
	Lower Meriden formation	?	?	?	?	3+
	Upper Meriden formation	15	55	8	21	
	Portland arkose	12	60	16	12	
Central Connecticut	Lower New Haven arkose (Basal)	20	80	—	—	
	Lower New Haven arkose (Higher up)	2	85	8	3	
	Upper New Haven arkose (W-area)	0	70	23	5	
	Upper New Haven arkose (E-area)	8	90	2	1	
	Lower Meriden formation	—	—	3	95	2
	Upper Meriden formation	Traces	23	25	51	1
	Portland arkose	13	58	24	7	

Percentage Ratio of Red Beds in Different Rock Types

		Total	Conglomerate	Sandstone	Siltstone	Shale	Limestone
General	New Haven arkose	45	—	40	100	100	—
	Meriden formation	52	—	60	90	46	—
	Portland arkose	63	—	61	100	70	—

Percentage Ratio of Strata Bearing Animal Tracks

		Conglomerate	Red sandstone	Gray sandstone	Silt-stone	Maroon shale	Dark shale
Southern Connecticut	Upper Meriden formation	0	10	19	—	50	28

The northern and southern facies can also be differentiated by the relative coarseness of the sediments. As a whole, the sediments in southern Connecticut are much coarser and thicker than the equivalent horizons of central Connecticut. This change in facies is shown in Figure 5. In addition, it has been found that there is a notable change in mineral composition between these regions.

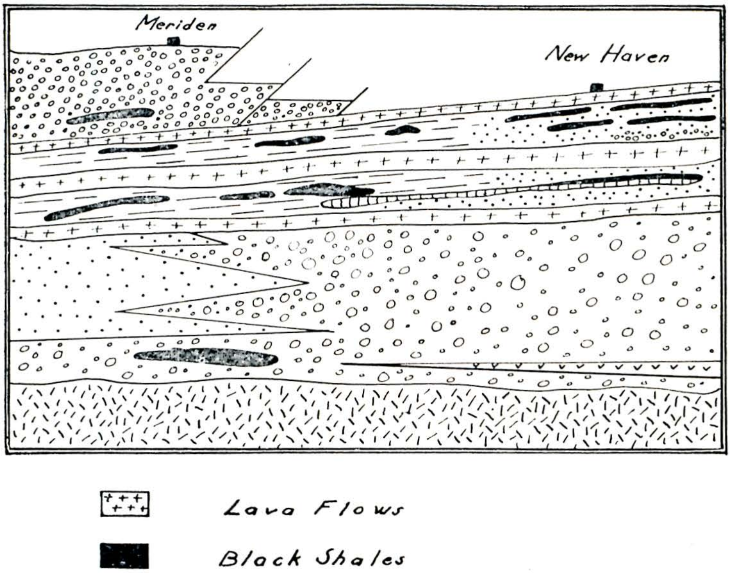


Figure 5. General north-south section showing changes of facies between southern and central Connecticut. Note decrease in coarseness going from New Haven (southern Connecticut) toward Meriden (central Connecticut).

Mineral Zones

A further division of the three main Triassic formations into members on the basis of field evidence alone is possible, but difficult, excepting for the Meriden formation, which can be conveniently divided into a lower and an upper sedimentary member by the middle lava sheet. It has been found that a division of the New Haven arkose and the Portland arkose into several members can be accomplished best by a zoning on the basis of changes in heavy minerals. It has also been found that these mineral zones can be generally correlated with lithologic changes observable in the field.

The central Connecticut facies of all three of the Triassic formations is characterized by the presence of indicolite (deep blue tourmaline), which is ubiquitous at all horizons and was present in every specimen examined, without a single exception. The southern Connecti-

cut facies is characterized by the almost complete absence of indicolite [3] and by the presence, within the stratigraphic range of the New Haven beds, of epidote and a high ratio of pink to colorless garnet, whereas in central Connecticut, the reverse is true (no epidote and a low ratio of pink to colorless garnet).

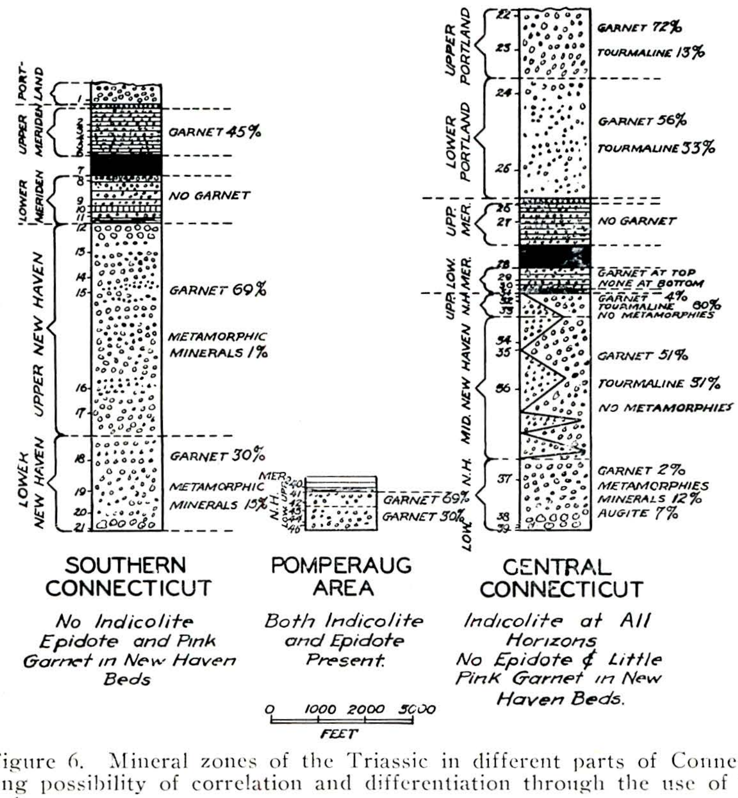


Figure 6. Mineral zones of the Triassic in different parts of Connecticut, showing possibility of correlation and differentiation through the use of heavy minerals.

Table 4 C shows the mineral composition of a suite of typical rock samples and Table 5, the zoning arrived at on the basis of the mineral analyses of Table 4 C. Figure 6 shows the same zoning presented in graphic form together with a stratigraphic distribution of the localities of Table 4. Figure 7 shows the geographic distribution of these localities.

Further details as to the zoning of the different formations are given in the respective descriptions of these formations.

[3] Only 4 grains of indicolite observed in southern Connecticut and at the only two horizons (basal New Haven and lacustrine lower Meriden) when the drainage pattern favored a supply of material from central Connecticut. See chapter on Sedimentation.

Thickness

The thickness of the Triassic rocks of Connecticut is variable: They reach an aggregate thickness of 16,500 or 17,000 feet in the eastern part of the basin along the Great Fault and decrease to 1,250 feet in the Pomperaug area, near the westernmost extremity of the original Triassic trough of sedimentation. The large Triassic homocline has been broken up by numerous block faults and this makes a measuring of the exact thickness very difficult. However, a deep well drilled on the grounds of the Winchester Repeating Arms Co., went through 4,000 feet of Triassic rocks and did not reach the crystalline basement (Gregory, 1904, p. 147). As this well was drilled at a locality where the thickness of the Triassic section has been estimated to be only around 5,000 feet, it seems that the great thickness postulated for the Triassic rocks is reasonably accurate. A generalized description of the section and the estimated thicknesses are given in Table 2 and Figure 5.

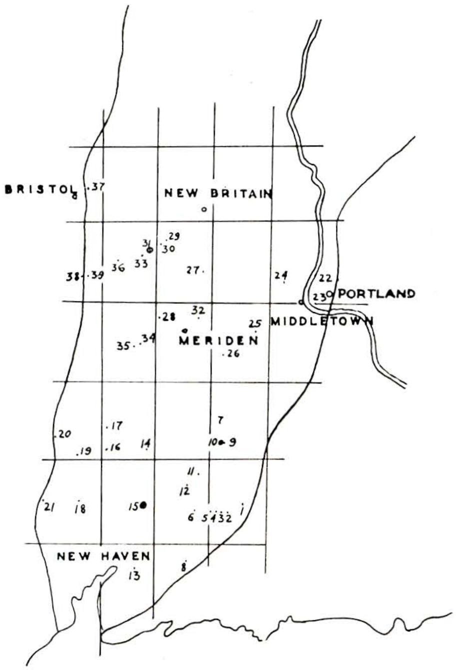


Figure 7. Geographic distribution of typical localities analyzed in Table 4. Localities at which quantitative angularity studies were made (see Figure 23) are marked by black dots.

New Haven Arkose

General Features

Distribution. The New Haven arkose (the "Western Sandstone" of Percival) occupies the western part of the Connecticut Valley. It

is developed most fully in the New Haven region. Because of the difference in facies, it is necessary to provide more than one type locality. In southern Connecticut the New Haven beds are exposed best along the western slope of West Rock ridge (basal conglomeratic arkose, locs. 19 and 21); in Hamden, at the northern end of Whitney Avenue (pale arkose and red siltstone, middle part of the section, loc. 17); on the Hartford Turnpike, next to the New Haven Country Club (conglomerate and very coarse pink arkose, upper part of the section); and in the quarries of Fair Haven (pink arkose, upper part of the section, loc. 13). These four exposures represent the four typical lithologic variations of the New Haven beds in southern Connecticut.

In central Connecticut, the basal conglomeratic arkose can be seen at Roaring Brook in contact with the underlying crystalline rocks (loc. 39), and the balance of the section, made up of interfingering coarse white arkose and fine brick-red sandstone, is typically exposed at Hanover Pond, south of Meriden.

Thickness. In central Connecticut, west of Meriden, where there is apparently no duplication of strata by faulting, the thickness of the

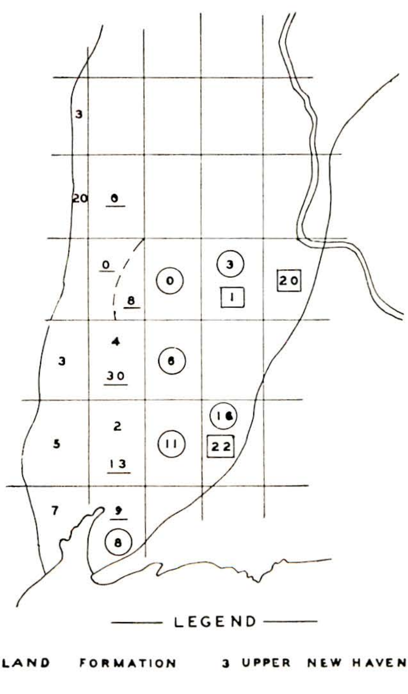
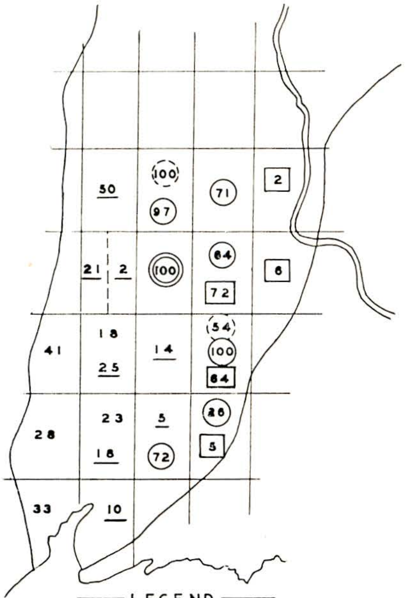


Figure 8. Geographic and stratigraphic distribution of conglomerates. Numbers indicate what percentage of a given formation is made up of conglomerates in that particular rectangle; and symbols around numbers indicate the formation according to the legend.

New Haven arkose can be measured at 5,000 to 5,500 feet. In the New Haven region, the apparent thickness is much greater, 9,000± feet in the median part of the valley, but a certain part of it is probably due to repetition by faulting. However, a thickness of 6,500 to 7,500 feet is probable for the eastern portion of the area covered by the New Haven beds, i. e., in the Montowese-Northford district. The thickness of the buried portion of the New Haven arkose near the Great Fault possibly may exceed 8,500 feet.



LEGEND

1 PORTLAND FORMATION — 4 UNDIFFERENTIATED MERIDEN

2 UPPER MERIDEN FORMATION — 5 UPPER NEW HAVEN ARKOSE

3 LOWER MERIDEN FORMATION — 6 LOWER NEW HAVEN ARKOSE

Figure 9. Geographic and stratigraphic distribution of siltstones and shales. Numbers indicate what percentage of a given formation is made up of these fine clastics in that particular vicinity; and symbols around numbers indicate the formation according to the legend.

Correlation. The New Haven arkose appears to be the stratigraphic equivalent of the Sugarloaf arkose of Emerson in Massachusetts and of the South Britain conglomerate of Hobbs, in the Pomperaug basin.

Character. In the region of its typical development, i. e., in southern Connecticut, the New Haven arkose is represented mostly by a coarse arkose of changing color, angularity, sizing and sorting, with interbedded subordinate layers of a fine-grained red micaceous silt-

TABLE 5

ZONING OF THE TRIASSIC INTO HEAVY MINERAL HORIZONS

SIGNIFICANT AVERAGE MINERAL FREQUENCIES

Area	Horizon	Indicolite	Epidote	Monazite	Kyanite	Hornblende	Staurolite	Sillimanite	Zoisite	Garnet	Ratio of pink garnet to total	Rutile	Tourmaline	Zircon	Augite	Ratios of iron ores to rare minerals	Ratio of tourmalines: brown: pink: green
Southern Connecticut	Upper Meriden	—	—	4.6	0.1	0.1	0.2	0.1	—	44.6	19	1.9	30.6	6.3	—	45:55	69: 6:25
	Lower Meriden	0.2	0.1	1.3	0.2	0.2	0.9	0.1	0.1	0.5	—	3.8	59.8	14.0	—	52:48	28:30:38
	Upper New Haven	—	3.5	1.4	0.1	0.2	1.1	—	—	69.0	32	0.5	6.2	2.2	0.4	30:70	47:12:41
	Lower New Haven	0.1	14.8	0.3	2.8	4.3	6.0	0.1	1.5	29.8	37	2.2	14.0	13.8	0.2	40:60	50:14:35
Central Connecticut	Portland arkose (E.)	1.5	6.5	—	—	0.5	—	0.2	1.0	72.0	20	2.0	13.5	0.2	—	23:77	80: 7:13
	Portland arkose (W.)	1.5	—	—	—	—	—	—	—	56.0	3	7.0	33.0	0.7	—	22:78	90: 2: 8
	Upper Meriden	5.0	—	2.0	—	—	—	—	—	0.3	—	19.0	67.0	6.0	0.3	——	89: 1:10
	Lower Meriden	0.7	1.0	0.2	0.4	1.6	5.8	0.2	1.0	11.4	—	8.0	32.0	17.8	0.2	——	62:13:25
	Upper New Haven	2.5	—	2.0	—	—	—	—	—	4.0	22	5.5	60.0	14.5	—	48:52	87: 5: 8
	Middle New Haven	1.7	—	0.7	0.1	—	0.1	0.3	—	50.7	6	5.0	31.0	8.0	—	18:82	87: 5: 8
	Lower New Haven	13.0	2.5	—	1.4	3.8	6.7	0.3	0.1	2.1	13	3.3	42.3	14.7	6.7	62:38	73:10:17
Pomperaug	Lower Meriden	—	—	0.3	0.3	—	2.0	—	—	12.0	0	5.0	5.0	74.0	—	77:23	10: 0:90
	Upper New Haven	0.5	—	0.4	0.1	—	0.7	—	—	68.5	8	3.0	15.5	11.0	—	33:67	77:13:10
	Lower New Haven	3.8	0.3	3.3	0.2	0.5	1.1	—	—	30.0	9	4.7	42.3	11.0	—	51:49	77:10:13

stone, which frequently, but rather loosely, has been referred to as a "shale". Generally, in the lower part of the section, the arkose is grayish, whitish purple, or mottled; in the upper part it is generally pink or red. Beds and lenses of conglomerate are locally abundant, especially near the very base of the section and again close to the top.

In central Connecticut the pale-colored basal conglomeratic arkose is also present, but the greatest part of the section (4,000 + feet) consists of an alternation of coarse, in places conglomeratic, grayish-white or pink arkose and medium- to fine-grained brick-red clayey feldspathic sandstone. The brick-red sandstone predominates west of Meriden, the pale arkose east of Meriden and in the vicinity of the city, both types are intimately interlayered.

As a whole, conglomerates form 9 per cent of the New Haven arkose; arkoses and sandstones, 76 per cent; siltstones, 13 per cent; and shales, 2 per cent. Forty-five per cent of the section is red. Table 3 gives more detailed information on the lithology for the different facies and horizons of the formation and Figures 8 and 9 present the geographic variations in lithology (see also Figures 16 and 17).

Cross-bedding is abundant and mud cracks and ripple marks are common in the finer-grained beds.

Mineral horizons. It is possible to divide the New Haven arkose, according to its lithology, into an upper and a lower member, with a basal conglomeratic layer at the bottom of the lower member. The same divisions can be made everywhere on the basis of the heavy mineral content and in addition, in central Connecticut, it is possible to divide the upper member into two additional mineral zones, thus providing a threefold division of the formation.

Table 6 summarizes the changes in the frequencies of the more important minerals. It shows that the especially significant changes in frequency occur in the garnet, on the one hand, and in the metamorphic group of minerals (kyanite, hornblende, staurolite, sillimanite and zoisite) on the other.

As a result, it is possible to divide the New Haven arkose in southern Connecticut into two principal zones:

1. A lower member characterized by a moderate amount (30 per cent) of garnet and a notable amount (15 per cent) of metamorphic minerals; and

2. An upper member characterized by a very high amount (60 per cent) of garnet and an almost complete absence (1 per cent) of metamorphic minerals.

In central Connecticut a triple division of the New Haven arkose is possible:

1. A lower member characterized again by a notable proportion of metamorphic minerals (12 per cent) and a low amount (2 per cent) of garnet.

2. A middle member characterized by a high garnet content (51 per cent) and no metamorphic minerals.

3. An upper member containing very little garnet (4 per cent), no metamorphic minerals and a high amount of tourmaline (60 per cent).

The presence of indicolite characterizes all horizons in central Connecticut, whereas the absence of this mineral is equally typical of southern Connecticut. In addition, the New Haven beds of southern Connecticut are characterized by epidote and a relatively high ratio of pink to colorless garnet (34 per cent), whereas in central Connecticut there is no epidote in the section outside of Roaring Brook and the ratio of pink to colorless garnet is much lower (13 per cent).

TABLE 6

AVERAGE FREQUENCY OF SIGNIFICANT MINERALS IN THE NEW HAVEN AND LOWER MERIDEN BEDS

	Lower New Haven arkose	Upper New Haven arkose		Lower Meriden formation
	Southern Connecticut			
Kyanite	2.8	0.1		0.4
Garnet	29.8	68.5		0.5
Epidote	14.8	3.5		0.1
Hornblende	4.3	0.2		0.2
Staurolite	6.0	1.1		0.9
Tourmaline	14.0	6.2		59.8
Zircon	13.8	2.3		14.0
	Central Connecticut			
		Middle	Upper	
Augite	6.7	—	—	0.2
Kyanite	1.6	0.1	0.2	0.4
Epidote	2.5	—	—	—
Garnet	2.1	50.7	4.0	1.3 (rises at top to 43%)
Hornblende	3.8	—	—	1.6
Indicolite	13.0	1.5	2.5	0.7
Staurolite	6.7	0.1	—	5.8
Tourmaline	42.3	31.0	60.0	32.0
Zircon	14.7	8.0	14.5	17.8
	Pomperaug Basin			
Kyanite	0.4	0.1		0.1
Garnet	30.0	69.0		12.0
Hornblende	0.6	—		—
Indicolite	4.0	0.7		—
Staurolite	1.2	0.8		1.5
Tourmaline	42.3	15.5		4.0
Zircon	11.0	11.0		74.0

Table 6 also shows the abrupt change in mineral frequencies that takes place between the top of the New Haven arkose and the base of

the Meriden formation. The decrease in garnet, the reappearance of the metamorphic group and the changes in the frequencies of tourmaline and zircon are notable. Very similar changes take place in the Pomperaug basin.

The reason for the difference between the lower and upper New Haven horizons is probably due to the fact that some time during the middle of New Haven time, erosion in the source area stripped off the cover of metamorphic rocks (Bolton schist) from the underlying igneous intrusions and their pegmatitic aureoles (Stony Creek granite, Glastonbury granite-gneiss, Lighthouse granite, etc.), The next change between New Haven and Meriden mineral frequencies probably resulted from a disruption of the drainage during the early Meriden lacustrine period.

Southern Connecticut Facies

Lower member. The lower New Haven arkose. 2,000 to 3,000 feet thick, consists of a coarse (1 to 3 mm.) white, gray and mottled arkose with subordinate layers of a finer grained (0.25-0.5 mm.) red micaceous shaly or silty sandstone 1 to 10 feet thick and locally, very small lens-shaped thin layers of dark or red shale, only a few inches in thickness. Arkoses form 67 per cent of the section, conglomerates 5 per cent and the shaly sandstones, siltstones and shales 28 per cent. A generalized stratigraphic section of the New Haven arkose between Mt. Carmel and New Haven is shown in Figure 10. This section is uncorrected for possible duplication by faulting and the total thickness is probably between 6,500 and 7,500 rather than the apparent 9.000 feet shown in the sections.

A much coarser arkose than the average is present near the base. In places it passes into a conglomerate with cobbles up to 10 cm. in diameter, the average being 3 to 5 cm. These basal beds are exposed at Dawson Lake, where the unconformable contact between the Triassic and the old crystalline floor was visible some years ago during the construction of a dam, but is now covered. At the present time a purplish-gray and brick-red conglomeratic sandstone is exposed in the gorge of West River, just below the dam. This outcrop (loc. 21) is located 350 feet east of the nearest exposure of Orange phyllite and stratigraphically not over 30 feet above the buried contact.

Pebbles up to 10 cm. in diameter, mostly quartz (milky, clear or smoky) are abundant. The sandstone is very coarse grained, angular and poorly sorted (Figure 11). The rock is made up mostly of quartz (88 per cent) with a little feldspar and fragments of quartzite. The quartz is either colorless, angular, often showing freshly broken edges (predominating type), or opaque, milky white, usually subangular, but showing all degrees of rounding. Several small, perfectly rounded and frosted quartz grains were found in the medium sand (0.5-0.25 mm.) fraction. The heavy mineral assemblage (Plate I-A) is charac-

terized by a flood of epidote and a notable amount of other metamorphic minerals (kyanite, staurolite, etc.).

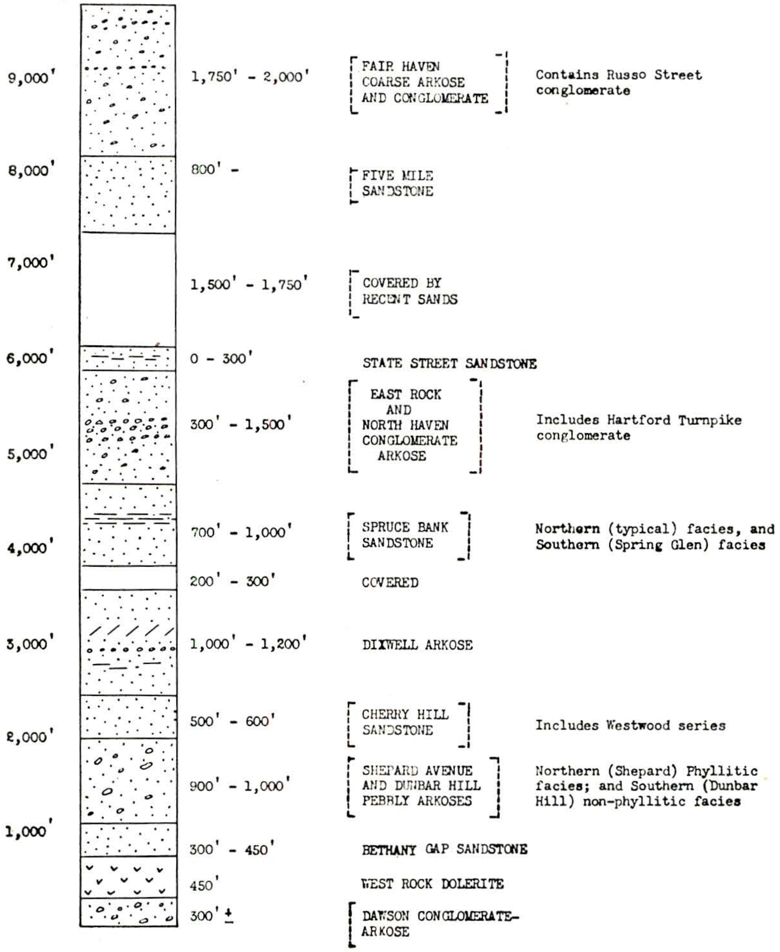


Figure 10. Composite stratigraphic section of the New Haven arkose in the New Haven region (southern Connecticut). The thicknesses of the different members are apparent and in many cases may be excessive, due to duplication of beds by faulting.

From there on there are very few more notable conglomerates until the very top of the New Haven formation, where small irregular pockets of conglomerate begin to appear again. The basal conglomerate and conglomeratic arkose are less than 300 feet thick. Their upper limit can be assumed to be the base of the West Rock sill.

At Mount Sanford (loc. 20) a gray sandstone, 300 feet above the base of the section and 20 feet below the sill of West Rock Ridge,

shows considerable hydrothermal (?) alteration and total replacement of the feldspars by sericite (28 per cent of the rock, Plate VII-A).

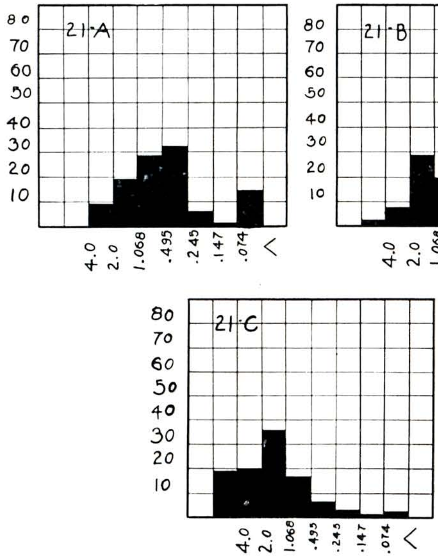


Figure 11. Histogram showing extremely rapid fluctuations in coarseness in the same arkose layer within a 9-foot stratigraphic range of the basal Triassic (loc. 21).

Immediately above the West Rock sill, the number and thickness of fine sandy, silty and shaly layers increase considerably and for approximately 300 feet they constitute no less than 35 per cent of the section. This zone of relatively abundant fine-grained members is difficult to describe or to differentiate with precision, but it appears to be present on the eastern slope of West Rock Ridge from its southern end to Bethany Gap.

The rest of the lower New Haven beds consist of the typical pale-colored arkose with subordinate red silty and shaly members. This arkose weathers to a peculiar purplish gray. There are many local variations, but they are all due to lenses which grade into each other, both stratigraphically and geographically. The upper part of the lower New Haven, especially in its northern area (roughly north of an east-west line running one mile north of the junction of Dixwell and Whitney avenues in Centerville), is characterized by the presence of numerous fragments of chlorite or phyllitic slate, which, locally, as in the outcrops on Shepard Avenue (loc. 17), constitute as much as 15 or 20 per cent of the rock (Plates XX-A and XXIX-C).

This part of the section contains several interesting exposures, including a 60-foot outcrop on Dixwell Avenue (east side, near Weybosset Street) which exposes an ancient Triassic river channel (loc. 17a).

Fifteen feet of strata are exposed. The dip is 14° to the SE (140°). The beds are cross-bedded, and show prominent cut-and-fill stratification, with lensing out, taking place both longitudinally and laterally. The surfaces of the layers are eroded and filled with conglomeratic pockets. The angle of cross-bedding is 35°. The main current, as in-

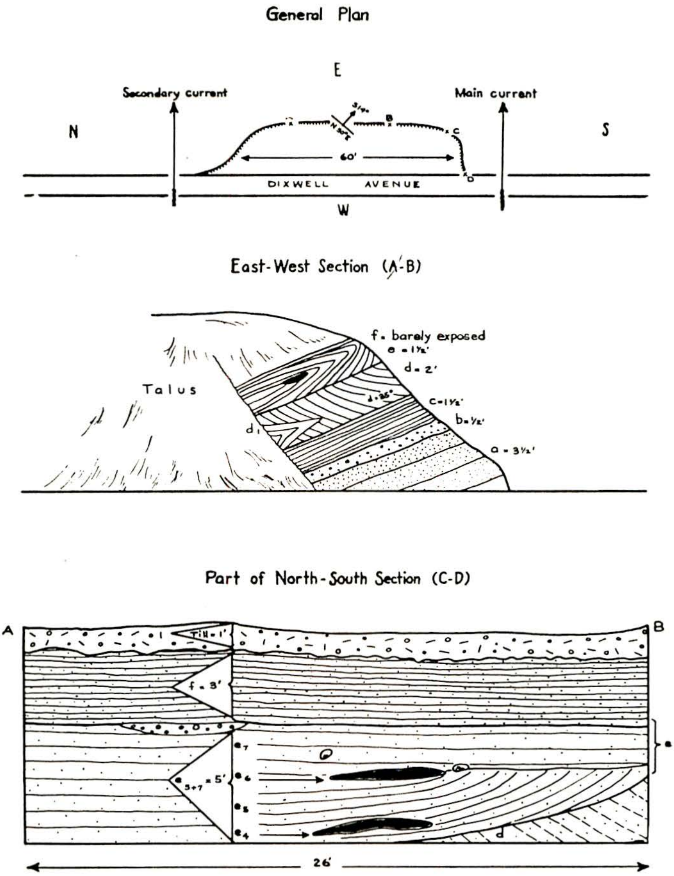


Figure 12. Sketch of exposure of New Haven arkose at loc. 17a on Dixwell Avenue. Outcrop is on east side of street and shows two types of cross-bedding. The principal cross-bedding indicates a main westward current whereas the subordinate cross-bedding suggests a minor eastward reversal of the current. (The main current arrow at top points erroneously east instead of west.)

dicated by the cross-bedding, was southwestward or westward, but minor reversals to the east, as shown at one place by pebble imbrication, took place. A sketch of this channel is shown on Figure 12. See also section on page 47.

Organic material is less uncommon in the lower New Haven arkose than is generally realized. However, it always occurs as very

small black shaly pockets and lenses which lose their color rapidly, upon weathering. A typical occurrence of that kind is the outcrop at Dunbar Hill (loc. 18) where a section which dips 15° to the SE (150°) is exposed. This section (shown below) represents not a typical fluvial deposit, but rather one of a semi-lacustrine character (possibly a small pond?).

Upper member. The upper New Haven arkose (4,000 to 5,000 feet thick) consists of a coarse (1-3 mm.) pink or red arkose carrying fragments of Stony Creek granite and other granitic rocks, with subordinate layers of micaceous shaly sandstone. Numerous lenses of conglomerates are present. These lenses can be roughly assigned to

Section at loc. 17a, Dixwell Avenue, Hamden

Glacial till

f. Pinkish white, medium (0.25 - 1 mm.) angular arkose, locally coarse (1 - 5 mm.). Contains abundant muscovite and biotite. Pebbly (quartz, white granite gneiss, feldspar, schist) with pebbles averaging 1-2 cm. and up to 3-4 cm. Banded 1-3 cm. Overlies unconformably rest of section .... 3 ft.

e. Mottled (pink, with white and pale green) arkose, medium-grained (av. 0.5 mm., up to 1.5 mm.), angular, with much biotite. Contains many pebbles of green chloritic schist and in smaller amounts granite gneiss, quartz and feldspar and very large mica flakes. Interbedded with several lenses (E5 and E7) of a dark fine silty shale, finely but irregularly laminated. Shale beds 6 to 20cm. thick, show black core and carbonaceous matter and reddish exterior. Over lies unconformably next member. Thickness variable (lensing)..1 ft. 6 in.- 5ft.

d. Coarse, whitish and pinkish angular arkose, cross-bedded at a 35° angle. Contains a lens (dl) of fine banded red and white, which pinches out to the southwest. Variable thickness .... 2 - 3 ft.

c. Variegated, pink, red, white medium (0.5 - 1 mm.) arkose finely banded (layers 1 cm. wide), separated by dark ferruginous bands 1 - 2 mm. thick. Lighter in color and coarser (1 - 3 mm.) near top .... 1 ft. 6 in.

b. Conglomeratic layer with pebbles up to 6 cm. in diameter (banded white gneiss, white granite gneiss, quartz, feldspar, chlorite-schist). Pebbles rounded and flattened .... 6 in.

a. Variegated whitish, greenish, or purplish-pink, coarse (1 - 2 mm.) arkose, soft, disintegrates easily into sand. Poorly banded (2 - 4 cm.), becomes coarser near top .... 3 ft. 6 in.

Total thickness exposed .... 15 ft. ±

Section at loc. 18, Dunbar Hill, Hamden

Top covered

f. Coarse (2 - 3 mm.) pebbly white, purplish near top. Contains pebbly layers; slightly micaceous; irregularly jointed; weathers to a dirty gray color .... 2 ft. 6 in.

e. Black silty shale, sandy and micaceous, thinly laminated, very fragile, weathers to an ashen gray color, turns reddish upon drying .... 4 in.

d. Yellowish-white, loose, poorly consolidated sand, fine to medium-grained (0.25 mm.) .... 3 in.

c. Red, micaceous sandstone, medium-grained (0.5 - 1 mm.) faintly ripple-marked .... 1 ft.

b. Black shale, as in (e) .... 1½ in.

a. Red sandstone as in (c) .... 2 ft.

Base covered

Total thickness exposed .... 6 ft. 2 1/2 in.

two horizons: a lower one passing through East Rock, North Haven and Wallingford and an upper one near the very top of the New Haven formation, stretching from Foxon Park to Northford. There are also several intermediate conglomerate pockets which, however, appear to be concentrated either in the Foxon Park-East Rock region or in the East Wallingford-Northford district. The possible inference from this is, that besides two general periods of conglomerate formation, two rather important and relatively swift drainage courses may have existed in these areas during most of upper New Haven time. The upper New Haven beds weather to a red or purplish color.

Section at loc. 16, Westwoods Avenue, Hamden

(see also Fig. 4)

Glacial till	
Coarse conglomerate	1 ft. 6 in.
Coarse whitish arkose massive or layered into bands 2-5 mm. thick	3 ft. 4 in.
Red silty shale	2 in.
Fine to medium, layered (2-3 cm.) gray arkose, weathers reddish	1 ft.
Red shaly sandstone, passes into real shale near base, layered (1-2 cm.)	8 in.
Coarse whitish massive arkose	10 in.
Red shale, lenses out	2 ft. 6 in. to 6 in.
Coarse gray massive arkose	1 ft. 8 in.
Red shaly siltstone, lenses out	1 ft. 3 in.
Coarse gray massive arkose	1 ft. 3 in.
Talus	10 ft.
Red sandy shale	2 ft. 6 in.
Coarse, pebbly, gray arkose (as at loc. 17), layered (2-10 cm.)	7 ft. 1 in.
Red shaly siltstone	1 ft. 3 in.
Coarse, pebbly, layered, gray arkose	10 ft.
Medium to coarse gray arkose, contains many small red shaly lenses (35%)	5 ft.
Red shaly siltstone	10 in.
Talus	7 ft. 8 in.
Coarse, layered, gray arkose, interbedded with shaly lenses (20% of the rock)	4 ft. 7 in.
Total thickness	63 ft. 1 in.

Section at loc. 13b, Russo Street, Foxon

Pebbly arkose	10 ft.
Conglomerate	1 ft. 6 in.
Pebbly arkose	1 ft.
Conglomerate	1 ft. 6 in.
Pebbly arkose	8 ft.
Conglomerate	1 ft.
Pebbly arkose	7 ft.
Conglomerate	1 ft.6 in.
Pebbly arkose	30 ft.
Total thickness	61 ft. 6 in.

A transitional zone between the lower and upper member of the New Haven arkoses extends throughout Hamden east of Whitney Avenue. A typical outcrop is present at Westwoods Avenue (loc. 16) dipping 16° SE (140°). A sketch of this prototype fluvial locality is shown on Figure 4 and the section is described on this page.

The typical upper New Haven arkose is exposed best in Fair Haven and the conglomeratic beds north of East Rock and in Foxon. The Fair Haven quarries (loc. 13) expose a real "textbook" type of arkose, entirely granitic in appearance and in composition, traceable through its heavy minerals (monazite and large smoky zircons) to the Stony Creek granite. Finer beds of siltstones and sandy shales, ripple-marked and mud-cracked, are present. A skeleton of *Stegomus arcuatus* was discovered in these quarries.

A good outcrop on the Hartford Turnpike (loc. 13a) east of the New Haven Country Club shows a remarkable development of large lenses and pockets (up to 7 feet thick) of conglomerates in a coarse arkose. Another good outcrop on Russo Street in Foxon (loc. 13b) shows, as described on the preceding page, an alternation of arkose and real conglomerate beds.

East of Wallingford, thick brick-red sandstones interbedded with shaly siltstones are present, and at some places they are also interbedded with coarse conglomerates and grayish arkoses. This alternation is somewhat similar to the alternation of red sandstones and white arkoses around Meriden, to be described later on.

Central Connecticut Facies

Lower member. The lower beds of the New Haven arkose, approximately 1,000 feet thick, are made up of white or gray arkoses, conglomeratic near the base. At Roaring brook (loc. 39) the basal Triassic beds overlie, unconformably, the old crystalline floor. This classic locality is the only place in Connecticut where this undisturbed contact can be always observed. The crystalline floor, built up of truncated, steeply tilted (75°) layers of Hartland schist, is overlain by gently dipping (8° to 12° to the SE) Triassic beds (Plate VI-A). From the dip and the local geomorphological character of the Western Highland, Longwell concludes that a large fault is present in the Hartland schist *west* of the contact. The outcrop extends, with some interruptions, for over 1,000 feet along Roaring Brook and an aggregate thickness of more than 100 feet of basal Triassic beds is exposed. The Hartland schist below the contact consists of:

1. Micaceous members — garnetiferous mica-schist composed of large foliated and crumpled muscovite and biotite flakes, with red garnets up to 2 mm., standing out on weathered surfaces. The heavy residue is characterized by a flood of staurolite (both clear and cloudy types with carbonaceous inclusions) and an appreciable amount of iron ores and anatase.

2. Quartzitic members — very fine-grained quartzose mica-schist, almost imperceptibly layered. The heavy residue is characterized by a flood of idiomorphic brown tourmaline, by a high percentage of colorless garnet and by a notable scarcity of iron ores. Tourmalinization induced by pegmatites close by seems to be the cause of this.

3. Pegmatitic quartz veins, consisting of granular quartz, either colorless (water-clear) or dull white, sprinkled with biotite and muscovite flakes and a very few crystals of epidote. The quartz shows very weak strain shadows and contains rather scarce inclusions consisting mostly of minute gas or fluid cavities, some with free bubbles, often elongated and arranged in oriented chains or rows.

The micaceous members do not effervesce with cold HCl, but upon boiling with HCl lose a certain amount of ferruginous material (not computed quantitatively). The quartzitic members effervesce with cold acid. The loss in cold HCl is 5 1/2 per cent (calcareous cement) and a further loss in boiling HCl is 2 1/2 per cent (ferruginous cement).

The basal beds of the New Haven arkose rest upon the roughly beveled surface of the Hartland schist (Plate XX-B). They consist of layers and lenses of conglomerates, pebbly arkose and coarse arkose. The prevailing color is a whitish yellow or whitish gray with infrequent reddish brownish stains on weathered surfaces. These basal New Haven beds are made up of:

1. Conglomeratic layers composed of pebbles up to 10 cm. in diameter. The pebbles consist of quartz pebbles (75 per cent), gneiss and schist pebbles (20 per cent) and large feldspar crystals (5 per cent). The quartz pebbles are mostly very angular, but one in fifteen shows excellent rounding. The gneisses and schists are all somewhat rounded and flattened (Table 7). There is no apparent sizing, sorting, or layering. Some of the milky white quartz pebbles appear to have been derived from pegmatite veins in the underlying Hartland schist, but a microscopic study disproves this.[4] The quartz of the pebbles shows much more intense strain shadows and more abundant inclusions than the quartz of the local veins. The color and translucency of the quartz depend upon the abundance of minute inclusions.

2. Arkose — poorly sized and sorted. Contains considerable calcareous cement: 29 per cent of the rock is soluble in cold HCl after violent effervescence and 1 1/2 per cent is soluble in boiling HCl (ferruginous or dolomitic material). In a thin section, the arkose shows the following composition:

a. Quartz, angular quartzite and mica-schist fragments intensely deformed, angular grains of vein quartz with moderately undulose extinction and oriented inclusions and a few rather small rounded grains with no strain shadows. Total quartz in rock is around 50 per cent.

b. Microcline and plagioclase (albite-oligoclase). The feldspars vary greatly in freshness, most of them being sericitized and es-

[4] This has been recognized by Percival, but not by later observers. Percival (1842, p. 430) writes: "For although a coarse conglomerate occasionally occurs in the Western part of those basins, yet its fragments are usually more abraded and less easily referable to the adjoining Primary formations."

TABLE 7

PEBBLES FROM LOC. 39, ROARING BROOK

Basal New Haven conglomeratic arkose directly above contact with Hartland schist

1. Angular piece, 5 by 3.5 by 3 cm., colorless or pale-gray quartz, brilliant (greasy) luster. Consists of coarsely granular (2-5 cm.) vein quartz with crystals of black tourmaline up to 5 by 2.5 mm. Surface dark gray, subangular, fairly smooth to the touch. Thin section M4-1A-P1.

2. Angular equant piece, 10 by 7 cm., dull milky-white to light smoky-gray quartz. Coarsely granular (0.5-1.5 cm.) vein quartz with a few flakes of muscovite or bleached biotite. Angular surface, in places coated with ferric oxide. Thin section M4-1A-P2.

3. Flattened pear-shaped, somewhat rounded piece 9 by 6 by 3 cm. Quartzitic mica-schist or mica-gneiss composed mostly of dull-gray quartz and muscovite.

4. Flattened rounded pebbles, broken, present size 7 by 7 by 3.5 cm. Former length probably up to 10 cm. Coarse layered quartzitic gneiss, somewhat more quartzose than No. 3. Surface either smooth or rough, possibly indented from pressure of other pebbles.

5. Subangular equant piece 6 by 5 by 3 cm. Brilliant smoky-gray quartz; no inclusions visible; surface either smooth or rough.

5A. Triangular piece, equilateral sides 5 cm. long, 2 cm. thick. Pale smoky-gray quartz. Corner edges in places rounded, in others angular.

6. Similar material, pear-shaped, 6 by 3 by 1.5 cm

7. Equant pebble, 3 by 3 by 2.5 cm. Rounded on 3 edges, angular on other 3. Banded (1 mm.). White feldspathic quartzose gneiss, fine-grained, almost a layered quartzite.

8. Angular, triangle-shaped pebble 8 by 4 by 4 cm. Dull smoky-gray quartz, coarse-grained with small mica flakes. Rough surface.

9, 10, 11, 12. Angular pieces of dull smoky-gray to blue quartz. Dimensions from 3 by 2 up to 6 by 4 by 2 cm. Rough surface.

13, 14, 15, 16. Small angular or flattened pebbles of milky-gray or smoky quartz. Dimensions 3 by 1 by 1.5 cm., and less. The most flattened pebble (No. 15) is 3 by 2 by 0.75 cm.

17. Well rounded quartz pebble, 3 by 2.5 by 2 cm. Rose or brownish smoky-gray quartz.

18, 19. Angular feldspar pebbles (microcline or orthoclase). Broken, present dimensions 2 by 0.5 by 0.5 cm., and 2 by 1.5 by 1 cm. Original length believed to have reached 3 or 4 cm.

20. Rounded medium-grained layered quartzite pebble 6 by 4 by 3 cm. Surface rough.

SUMMARY

Quartz —-15 pebbles, 1 well rounded, others angular.
Foliated rocks — 4 pebbles, all subangular to rounded and flattened.
Feldspar — 2 pebbles, angular.

---

pecially replaced by calcite. Total remaining feldspar is around 20 per cent.

c. Calcite, 25-30 per cent of the rock, replaces feldspars and biotite.

Some of the quartz grains are strongly fractured and the fissures filled with calcite (Plates VI-A and VI-B). Iron-oxide stains in the

rock are due to the running of iron ores. Under the binoculars the cleaned, loose grains appear to consist mostly of opaque, milky quartz, two-thirds of them being subangular to angular and the balance either very sharply angular or fairly well rounded, some extremely so.

In addition to the minerals listed in the heavy residue table (loc. 39), perfectly fresh crystals of biotite were found preserved in the interior of large quartz grains. The heavy residue is characterized by an abundance of indicolite, brown tourmaline and augite and by an extremely varied suite of zircons, many of them rounded (rounded by abrasion, not just apparently rounded through the multiplication of vicinal faces).

The New Haven arkose 60-75 feet above the contact (loc. 38, approximately 750 feet west from the previous locality) shows good stratification and cross-bedding indicating alternating westward and eastward currents. The color of the rock is white with yellowish stains. The arkose does not react with cold HCl, but loses 8 per cent upon boiling and decantation in acid (ferruginous cement, some kaolin and some sericitic matter).

Under the microscope, the rock appears to be poorly sized and angular, with an absence of the well rounded grains found in the basal beds. The cement is not calcareous, but sericitic and argillaceous, with some iron oxide. The rock consists mostly of quartz (vein quartz and mica-schist and meta-quartzite fragments), microcline (two varieties according to the sharpness of the grating), some of the latter strongly altered, and plagioclase (albite-oligoclase). Large muscovite flakes are bent and exhibit intense undulose extinction. Some of the quartz grains are weakly fractured and the thin fissures filled with sericite. The fracturing and mineralization, however, are much less well developed than in the basal layers. The heavy residue is characterized by a flood of barite (60 per cent) with numerous dark inclusions. Indicolite, brown tourmaline and especially augite are also abundant.

The following conclusions appear justified:

1. The injection of the pegmatite veins into the Hartland schist took place in the Roaring Brook region subsequent to the period of metamorphism.

2. The Hartland schist was reduced to a very flat surface before Triassic deposition began. This peneplane was covered by a sedimentary cover containing some exceedingly well rounded material, part of which may have been of eolian origin: perfectly polished, rounded grains were discovered in the medium sand fraction (0.5-0.2 mm.) of the basal beds at Lake Dawson. These rounded grains, however, may have been also derived from Paleozoic orthoquartzites (?).

3. The existence of a large fault west of the Roaring Brook contact, advanced by Longwell on physiographic and structural grounds, seems to be substantiated by:

a. Intense replacement and calcitization of the lower New Haven beds.

b. Fracturing of quartz grains in these basal beds and filling of the cracks with calcite.

c. Partial calcitization of the quartzitic members of the Hartland schist near the contact.

At Bristol (loc. 37) a north-south fault, with upthrow on the west running along the eastern face of Federal Hill, forms the contact between the Triassic and the Hartland schist. The fault plane was not actually observed, but was inferred on structural and geomorphic grounds (arkose dips into crystallines and face of hill is very steep) and also on the presence of quartz veins filling joints in the arkose. Samples were obtained from the Hartland schist and the lower New Haven arkose less than 100 feet apart at a point approximately 500 feet north of the Pequabuck River bridge. The throw of the fault has been computed at 1,200 feet in the Bristol mine, 3 miles to the north. At Federal Hill it is apparently less. The arkose is medium-grained, of pale grayish-buff color, well sized (0.25-2 mm.), with only a few larger quartz grains and feldspar granules sparingly disseminated throughout the rock. The rock is massive, and shows hardly any bedding at all. Joints and fissures are present and some of the latter are filled with quartz veins 0.5 to 1 cm. wide, with small quartz crystals growing inward from both walls of the vein. The heavy minerals of the arkose (analysis 37) show that it belongs to the lower member of the formation.

At Forestville, 1 1/2 miles east of Bristol and stratigraphically approximately 1,500 feet above the base of the Triassic, is exposed an unusual series of gray and black fine-grained feldspathic sandstones, siltstones and shales, containing organic matter. All members of this series are fine- or medium-grained and all are strongly micaceous. The section, which dips 13° east, is as follows:

Section at loc. 37a, Forestville

Talus covers top of section.	
Grayish, in places whitish, feldspathic sandstone, in places with carbonaceous matter, thinly bedded (2-8 cm.), with subordinate layers of red arkose and a little black shale	26 ft.
Talus-covered hiatus	23 ft.
Red to maroon siltstone	2 ft.
Red micaceous arkose	3 ft.
Dark-gray feldspathic sandstone with organic matter	8 ft.
Black shaly siltstone	1 ft.
Black feldspathic sandstone with carbonized wood fragments	3 ft.
Grayish-white feldspathic sandstone	8 ft.
Talus covers base of section.	

Section 74 ft. thick out of which 51 ft. are visible.

This section is extremely similar to any typical section through the upper Meriden swamp beds. The heavy minerals, however, show that these beds are of New Haven age. These dark shales can be seen

in exposures for approximately one-fourth mile along the strike, but pebbles coming from these beds have been picked up in lacustrine Pleistocene glacial sands as far as four miles south and one and one-half miles north of Forestville. This may indicate that the swamp-beds outcrop possibly extended for five miles or more in a north-south direction.

Upper member. In the vicinity of Meriden the upper division of the New Haven arkose shows a remarkable variation of facies. Due to vertical block faulting which brings to the surface the same stratigraphic horizons as far as six miles apart across the strike, these variations can be conveniently studied.

East of Meriden, between the town and Lamentation Mountain, the upper New Haven beds are made up of a coarse, gray or purplish-white arkose, in many places conglomeratic and containing an abundance of pink feldspar pebbles and phyllite fragments. These coarse pale-colored strata will be referred to as the "Lamentation arkose".

West of Meriden and especially between Southington and the Hanging Hills, the same horizon consists of a fine- to medium-grained bright red to brick red, micaceous feldspathic sandstone, in many places interbedded with siltstones and shales. This rock, to be called the "Redstone" (from its type locality on Redstone Hill), is totally different from the Lamentation arkose in appearance, color and sizing (Table 8). Due to the softness of the rock (high clay content), the topography of this area is subdued and outcrops are scarce and poor.

In the immediate vicinity of Meriden and to the south and southwest of this town an alternating succession of interlayered "Redstone" and Lamentation arkose is exposed. Excellent outcrops can be seen in the town itself, in South Meriden, at Hanover Pond and along the highway south of the Quinnipiac River (notably at Cheshire Street).

At Hanover Pond, a 40-foot cliff, 500 feet long, shows 25 feet of Redstone and 15 feet of coarse grayish arkose in a cyclic series of layers and bands. The photograph on Plate XXI-A shows the following succession:

Coarse gray arkose	6 ft.
Redstone	2 ft.
Coarse gray arkose with conglomerate at base	3 ft.
Redstone	6 ft.

At Cheshire Street in the Quinnipiac River gorge a highway cut 1,100 feet long and 25 feet high exposes approximately 220 feet of strata. The lower 100 feet consist of very coarse purplish-white Lamentation arkose with numerous pockets and lenses of conglomerate (Plate XXI-B). The upper 120 feet are made up of Redstone carrying in its midst a 6-foot layer of Lamentation arkose.

TABLE 8

CONTRASTED COMPOSITION OF TYPICAL REDSTONE AND LAMENTATION SPECIMENS IN IMMEDIATE PROXIMITY

COMPARATIVE MECHANICAL ANALYSIS

	C	A	R
Pebbles	21%	—	—
Gravel	41%	—	—
Coarse sand	25%	35%	5%
Medium sand	6%	35%	18%
Fine sand	} 5%	} 28%	15%
Very fine sand			12%
Silt			10%
Clay	1%	2%	43%

C = Lamentation conglomerate, loc. 34.
A = Lamentation arkose, loc. 32.
R = Redstone, loc. 35 (close to specimen C).

TABLE 9

PROXIMAL CORRELATION BETWEEN REDSTONE (RED) AND LAMENTATION ARKOSE (LAM.) BASED ON HEAVY RESIDUE (CHESHIRE STREET, LOCS. 34 AND 35)

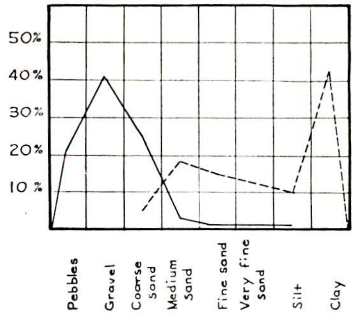
	Lam.	Red.
Chlorite	3	1
Garnet	54	56
Indicolite	2	1
Monazite	1	1
Rutile	5	7
Tourmaline, brown	18	20
Tourmaline, pink	2	1
Tourmaline, green	3	2
Zircon	10	12
Sillimanite	traces	traces
Kyanite	traces	traces

TABLE 10

LONG-RANGE MINERAL CORRELATION BETWEEN REDSTONE AND UPPER NEW HAVEN (LAMENTATION) ARKOSE; 50 FT. BELOW TOP

	Sandy fraction		Silty fraction	
	Lam.	Red.	Lam.	Red.
Anatase	5	4	11	8
Chlorite	traces	....	....	....
Garnet	2	7	traces	4
Indicolite	4	traces	5	1
Kyanite	....	....	....	traces
Monazite	2	2	traces	4
Rutile	6	6	5	12
Tourmaline, brown	57	54	47	42
Tourmaline, pink	4	2	1	1
Tourmaline, green	3	7	6	4
Titanite	1	2	1	1
Zircon	15	16	23	21

Lam.—Lamentation arkose; loc. 32.
Red.—Redstone; loc. 33 (5½ m. west of 32).



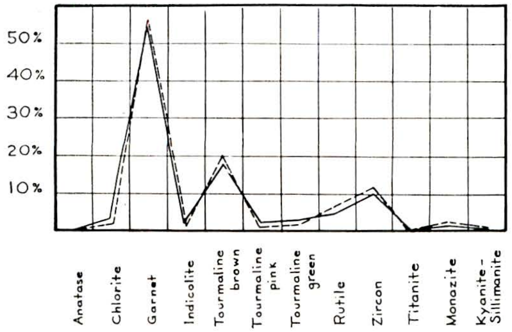


Figure 13. Proximal relationships between Lamentation (———) and Redstones (— — —) facies of the New Haven arkose at loc. 34 (see Tables 8 and 9).

Top: Mechanical analyses. Note wide textural and megascopic difference, indicating marked variations in the relative intensity of depositional processes.

Bottom: Heavy-mineral correlation, showing complete identity in composition, thus proving a common source area for both facies.

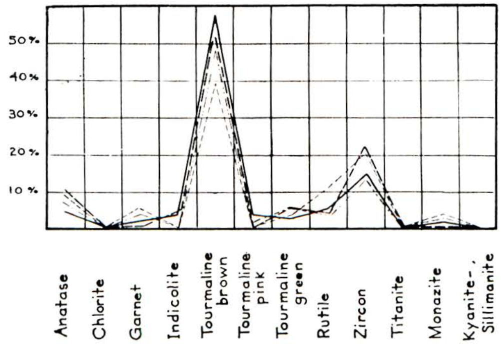


Figure 14. Long-range heavy-mineral correlation (see Table 10) between two different facies of the New Haven arkose, namely the Lamentation arkose at loc. 32 and the Redstone at loc. 33, about five and one-half miles west.

——— Lamentation arkose, sandy fraction

— — — Lamentation arkose, silty fraction

.. — .. — Redstone, sandy fraction

. . . . . Redstone, silty fraction

A microscopic study of the Redstone and the Lamentation arkose reveals that notwithstanding their totally different aspect, both these rock types are identical in composition and provenance at any given horizon. Samples from Cheshire Street—localities 35 and 34—disposed 550 feet apart and 100 feet away stratigraphically show identical assemblages of heavy minerals (Table 9). It must be added that these assemblages not only possess the same frequencies, but also have in common the same two types of zircon and the same three subvarieties of brown tourmaline.

A successful correlation can also be made over 5½ miles of territory across the strike between the type locality of the Lamentation arkose (loc. 32 on Route 5a) and a Redstone locality in Shuttle Meadow Pass (33). Both these exposures are approximately 50 feet below the lower lava flow, but the Redstone outcrop is 5½ miles north of west from the Lamentation locality. Megascopically no greater difference can be imagined between any two rock types. However, a careful study of the heavy minerals of both the sandy and the silty fractions from both specimens reveals again an identical composition and a common source. (Table 10 and Figures 13 and 14.)

The following conclusions can be made on the basis of the lithology, composition and distribution of the different facies of the upper New Haven arkose in central Connecticut:

1. The Redstone and the Lamentation arkose, although totally different in aspect, are nevertheless identical in mineral composition and provenance at any given horizon. The Lamentation arkose can be defined as sand and pebbles and the Redstone as the same sand and red clay.

2. The Redstone and the Lamentation arkose were derived simultaneously from the same source area, an area poor in rock types (one pegmatitic granite and one phyllite or chlorite-schist) and very limited in extent. The Glastonbury granite gneiss and the Bolton schist east of Middletown appear to be possible source rocks.

3. The Lamentation arkose with its numerous pebbles and boulders suggests violent erosion. The Redstone, with its 40 per cent of ferruginous clay, points strongly to intense chemical decay. Both these processes were taking place simultaneously over the limited area of the region of origin.

4. The streams which deposited the upper New Haven beds were flowing from east to west with no evidence of a north-south longitudinal drainage, as no foreign imported material is visible in the finer-grained sediments.

Meriden Formation

General Features

Distribution and thickness. The middle member of the Connecticut Newark forms a rather narrow belt of relatively soft rocks which occupies the central and east-central part of the Connecticut Valley.

It is exposed at its best between Meriden and New Britain. This Meriden formation (the "Middle Shale" of Percival) consists of the three lava sheets and the sedimentary rocks between. The thickness of the sedimentary members varies from 1,150 feet near Meriden to 2,000 feet east of New Haven. The three lava sheets are from 450 to 850 feet thick. A lower and an upper division (Davis's anterior and posterior shales), separated by the middle lava sheet, are present. The two type localities are:

1. For the lower division, the outcrop on the southern shore of Shuttle Meadow reservoir, between Meriden and New Britain (locs. 29 and 30). This is the lacustrine environment prototype (Fig. 4).

2. For the upper division, a quarry on a country road in Kensington, $1\frac{1}{2}$ miles south of Berlin (loc. 27). This is the swamp prototype (Fig. 4).

Character. In central Connecticut the lower division consists of 300 feet of exceedingly fine-grained, laminated fissile shales (so called "paper shales") showing an exceptionally well developed fine banding and layering. The lower 75 feet consist of red—or rather maroon—shales and siltstones weathering to a yellowish brown. Then follow approximately 60 feet of dark shales, in places bearing plants and fishes. These form the lower black shale horizon of Davis. However, few, if any, of these shales are really black. They are dark to light gray, blue or greenish gray, and weather to a rusty yellow. The dark shales contain, near their base, several very hard, thin (1 foot) layers of a siliceous blue limestone, and near their top, some thin (3 to 4 inches) bands of a pink dolomite and dolomitic siltstone. There is an abrupt change in color, but no apparent unconformity at the upper contact of the dark shales, and the upper 175 feet of the lower Meriden beds consists of red paper shales, very similar to the first 75 feet.

The upper division is somewhat coarser. The maroon paper shales gradually become more sandy and siliceous, and are coarser-banded. This change is rather gradual. After 600 feet, the upper dark shale horizon, 50 to 150 feet thick, makes its appearance. These upper dark shales are really a very complex unit, consisting of black and blue shales, in parts fossiliferous, dark siliceous lmiestones, and subordinate arkose and red shale layers.

The uppermost 150 feet of the Meriden formation is made up of hard siliceous red sandy shales, much more resistant to erosion than the overlying sandy members of the Portland arkose. When these two formations are brought in contact by faulting, the upper Meriden shales stand out and form well defined fault-line scarps.

In southern Connecticut the bottom of the Meriden formation cannot be distinguished at some places from the uppermost New Haven arkose, on the basis of lithology. It is the same pinkish, coarse arkose. However, this arkose, which is only locally present, does not exceed 100 feet in thickness, and passes rapidly into a fine-grained

highly micaceous platy shale which underlies a blue limestone 15 feet thick. This limestone is well exposed in a quarry near Northford, and has been traced for a distance of $1\frac{1}{4}$ mile south. Presumably, it extends much farther north, and is the equivalent of the lower blue limestone layers of the lower dark shales of central Connecticut. The limestone is followed by approximately 75 feet of dark shales, less well laminated than their central Connecticut equivalents. The top of the lower Meriden consists of 800 feet of a grayish pink, partly red, arkose of different degrees of coarseness, interbedded with layers of yellow sandy shale.

The change in lithology between the lower and upper divisions is distinct, and takes place immediately above the middle lava flow. The arkose becomes much finer (0.25 mm. or less), assuming a light gray or white color and containing layers of sandy shales. It weathers to a light yellow color with rusty streaks which appears to be typical of the upper Meriden arkose in both the southern and central Connecticut areas. After 400 feet, the arkose passes entirely into a complex series of red and black siltstones, arkoses, and shales, 500 to 600 feet thick, with several fossiliferous dark shale horizons. The top 100 feet of the section consists of red sandy fissile shales, when exposed away from the fault (Lake Saltonstall), and of fanglomerates if outcropping near the fault (Lake Quonnipaug).

Origin. As a whole, the Meriden sediments are very fine-grained (51 per cent of shales and siltstones) and do not indicate fluvial deposition. Their most notable feature is the widespread presence of dark organic and fossiliferous beds, commonly referred to as the "black shale" horizons.

This term, introduced by Davis, includes not only true black shales, but also bluish gray and dark gray shales, limestones, dolomites, grayish and greenish siltstones, and white, gray and black feldspathic sandstones, all of which are interbedded to some extent with red arkoses, siltstones, and shales, and in the vicinity of the Great Fault even with conglomerates and fanglomerates. The bedding, however, is rather thin and the finer, dark-colored sediments are a feature of almost every outcrop and permit an immediate identification of the series. Deposits of this type are universally present at least at two major horizons in the Meriden formation: immediately above the lower lava sheet and in the middle of the upper division of the Meriden beds. These two major dark shale horizons form a continuous cover over the whole Triassic basin of Connecticut, including the Pomperaug Valley, and their outcrops can be found without a single exception at the places where stratigraphy and structure require their presence. This continuity indicates that the Connecticut basin of deposition was entirely blanketed at least twice by dark sediments. The lower horizon consists to a very large extent of lacustrine deposits: perfectly banded and laminated dark and red shales, limestones, and very fine siltstones, partly organic, partly calcareous, partly (to a very minor degree) dolomitic. These lacustrine deposits extend from North-

ford to New Britain, and are also present in the Pomperaug area. They gradually pass into less perfectly banded and coarser variegated siltstones and arkoses.

The upper "black shale" horizon does not have such a marked lacustrine character, but consists of a bewilderingly complex juxtaposition of beds from limestones to arkoses, very lenticular in character, but homogeneous in their heterogeneity in the numerous exposures from Branford to the north of Massachusetts. Mud cracks in some of the black shales indicate sub-aerial exposure and suggest that the bodies of water, although numerous, were discontinuous and shallow. The general scarcity or even absence of definite lacustrine or fluvial features in these beds suggests that they are probably of swamp or marsh origin. An enormous, poorly drained marshy lowland composed of swamps, minor lakes, sluggish meandering streams, and patches of dry ground seems to have covered the Triassic basin during a large part of Meriden time.

The organic content of the black shales is very high. Some of the layers are strongly carbonaceous or even bituminous (the "fetid" beds of Percival). This has led to unfounded hopes, and resulted during the 19th century in several attempts being made to mine coal or obtain oil from the Meriden beds. These ill-fated enterprises, most of which took place in the Pomperaug area, have been described by Percival, Davis, Hovey (1892), and Hobbs (1901).

Central Connecticut Facies

Lower division. The lower lava flow is overlain in central Connecticut by a series of laminated, siliceous, maroon shales 75 feet thick. The shales are very fissile when slightly weathered (so called "paper shales"), but when fresh, they are hard, compact, and very difficult to crush. There are several orders of magnitude in the banding. The finest laminae are from 0.1 to 2.0 mm. thick, averaging 0.75 mm. These laminae unite into wider bands approximately 3 mm. thick. The latter finally form layers 1 to 3 cm. thick along which the rock breaks into hand specimens. The finest laminae often show cross bedding, lensing, and a cut-and-fill stratification. The planes of stratification are marked by flakes of muscovite. Shallow mud cracks, 2.5 to 5 cm. wide, and rill marks are present. This description can be applied to almost all the red shales of the Meriden formation.

These basal red shales are ovelain by a series, at least 60 feet thick, of dark (black, gray, green, and blue) perfectly banded shales, with subordinate siltstones, and a thin limestone layer near the base. The typical section of locations 29 and 30, at Shuttle Meadow reservoir, between Meriden and New Britain, is given below (graphic representation on Figure 4). The composition of these rocks is discussed in the chapter on Petrography.

The layering of these series is so perfect and rhythmic as almost to suggest varying. They show no desiccation marks and appear to be definitely of lacustrine origin.

The balance of the section is represented by pink and red siltstones and shales, well layered although less perfectly so than the dark beds. They show frequent ripple marking, curved laminations, and mud cracks, suggesting the presence of less permanent water bodies than those in which the darker beds were deposited. A section at Hubbard Park reservoir, Meriden (Plate XXIII-A), near the top of the series is described below.

Section at locs. 29 and 30, Shuttle Meadow reservoir

Note: All members show perfect fine banding, almost a varve-like effect. See sketch on Fig. 4. This is the lacustrine prototype.

	Talus	
l—	Fine-grained maroon siltstones and shales. In places show fine cross-bedding and cut-and-fill stratification. Faintly ripple-marked	14 ft.
k—	Greenish shale, in places cross-bedded and weakly contorted. Contain barite and pyrite crystals (1-3 mm. in diam.) and mica flakes on bedding planes	2 ft.
i—	Black shale	4 ft.
h—	Pinkish-gray dolomitic siltstone, with delicate, microscopic, cut-and-fill stratification. The planes of the latter are marked by the concentration of heavy minerals (siderite, indicolite, brown tourmaline, zircon, titanite, etc.)	2 in.
g—	Dark greenish-gray laminated (0.5-1 mm.) fissile shale, finely cross-bedded. Faintly ripple-marked. Contains pink calcareous layers up to 3 cm. in thickness	2 ft.
f—	Bluish-gray shale, somewhat less regularly banded than rest of section (obliquely curved laminae faintly cross-bedded). Contains much carbonaceous matter, some pyrite, and a little calcite	2 ft.
e—	Bluish-gray shale, with poorly preserved fish remains...	6 ft.
d—	Talus and break—approximately	25 ft.
c—	Black shale	2 ft.
b—	Bluish-gray impure limestone, layered, curved, and contorted	1 ft. 6 in.
a—	Dark-gray shale	2 ft.
	Total thickness exposed........	60 ft. 8 in.

Section at loc. 28, east of Hubbard Park reservoir, Meriden

Note: All layers are dark red or maroon in color, and contain small mudcracks.

	Talus	
g—	Silty, in places micaceous shale, finely laminated (0.5-2 mm.)	5 ft. 8 in.
f—	Fine-grained hard silty sandstone, interbedded with shale (10%), layers 1-6 cm. thick	1 ft. 8 in.
e—	Fine shale, crumbles into small fragments, contains in the middle a sandstone layer 4 inches thick	3 ft.
d—	Silty shale, as (g)	3 ft. 4 in.
c—	Fine sandstone, with shale layers, as (f)	2 ft. 6 in.
b—	Fine-grained sandstone, with no shale	1 ft. 8 in.
a—	Fine sandstone with shale layers, as (f)	1 ft. 3 in.
	Total thickness exposed	19 ft. 1 in.

Upper division. More than two-thirds of the upper Meriden beds (600 feet) consist of fine-grained siltstones and fissile siliceous shales, rather similar to the red basal shales of the lower division. They are exposed in many small outcrops between Meriden and New Britain. The upper part of the section contains a series of dark shales, arkoses, and limestones (the "upper black shale horizon" of Davis). An excellent exposure is present on the country road, 1½ miles south of Berlin and 1/3 of a mile west of Belcher Brook (loc. 27; section follows, illustrated on Fig. 4 and Plate XXIII-B). The distinctive features of these dark beds are their lensing, the small amount of desiccation marks, and their general heterogeneity, suggesting shifting but permanent water bodies (swamp environment).

Section at loc. 27, Kensington. 1½ miles south of Berlin

Glacial till

o—	Dark-gray, very hard, impure siliceous limestone, banded (2-4 cm.) and irregularly interlayered with a dark laminated shale (0.5-1 mm.) and in places with a black micaceous arkose. Limestone forms 75 per cent of the rock. Under the microscope it is seen to consist of a dark organic calcareous and micaceous paste rich in disseminated pyrite and very fine sand grains, and containing lenses and layers of somewhat coarser sand grains and large mica flakes	6 ft.
n—	Purplish-brown to maroon, very hard, very fine-grained siliceous siltstone, finely banded (0.25-0.5 mm.), in places massive (almost a chert), not fissile, slightly micaceous. Under the microscope appears to consist of a red clayey ferruginous and somewhat siliceous micaceous paste (85 per cent) in which are imbedded poorly sized grains of quartz, microcline, plagioclase, and quartzite fragments. Banding due to concentration of parallel mica flakes, with secondary calcite following these bands	8 ft.
m—	Dark-gray calcareous sandy siltstone, almost an impure limestone (calcite 40 per cent), banded into 3 equal layers. Contains abundant grains of quartz, microcline, and oligoclase. Banding due to contorted layers of organic mat- shale, very hard	2 in.
l—	Dark-gray laminated, micaceous, platy calcareous sandy shale, very hard	2 in.
k—	Yellowish-gray, fine-grained massive arkose. Poor parting caused by parallel mica flakes and flat black clay galls. Shows cut-and-fill stratification on a small scale. Under the microscope seen to consist of 48 per cent quartz and 52 per cent feldspar (mostly albite-oligoclase with very little microcline, somewhat kaolinized), pyrite, and large muscovite flakes. Grains closely packed together with no matrix. Variable thickness (lensing)	2 to 4 ft.
i—	Black laminated organic shale	6 in.
h—	Dark brownish-red laminated shale, fissile, in places almost a "paper shale". Under the microscope seen to consist of a dense, irresolvable micaceous and ferruginous paste of somewhat variable coarseness. These variations in coarseness seem to cause the banding (varved effect) .	1 ft. 6 in.

g—	Very dark-gray, almost black, weakly calcareous shale, laminated and contorted, faintly mud-caked	7 in.
f—	Black, very fine-grained micaceous feldspathic sandstone, almost a siltstone. Very hard. Under the microscope appears to be a microconglomerate with angular grains (45 per cent) of quartz (three-quarters) and fresh unweathered albite (one-quarter) imbedded in a matrix (55 per cent) made up of a dark organic paste, with a small amount of calcite	8 in.
e—	Black laminated shale	1 ft.
d—	Maroon fine-grained rock, in places a contorted micaceous siltstone (soft), in places a siliceous shale (hard). Under the microscope seen to be made mostly of a red ferruginous paste (65 per cent) in which are imbedded quartz and feldspar grains. Secondary bands of calcite follow the planes of stratification	2 ft.
c—	Purplish-red siliceous shale, very hard	1 ft. 6 in.
b—	Black calcareous shale, massive or in places laminated and contorted Shows small round depressions genetically dubious, suggesting gas bubbles rather than rain-pits (?)	1 ft.
a—	Black or very dark organic shale. Lower 3 feet massive, with a conchoidal fracture; upper 2 feet laminated (0.5-1 mm.). Contains small and irregular veins and pockets of calcite. Ripple-marked. Poorly preserved fish remains are present. Under the microscope seen to consist of a dense dark organic, partly micaceous paste, the fissility and parting being due to the parallelism of the mica flakes. Very few impurities (micro-lenses of minute quartz grains) and somewhat larger lenses of calcite	5 ft.
	Total actual thickness................	31 ft. 6 in.

The top of the section for over 150 feet is made up of fine siliceous shales and siltstones, as a rule very hard and resistant to erosion, much more resistant than the lower red siltstone and fine sandstones of the overlying Portland formation. This makes it possible, in some instances, to differentiate these two formations, when they are brought in contact by faulting, the Meriden siltstones then forming fault-line scarps in the shape of minor ridges.

Southern Connecticut Facies

Lower division. The lower lava flow is generally followed in southern Connecticut by a coarse arkose, which, in a hand specimen, is hardly different from the arkose under the same lava flow. Outcrops of this lowest member of the Meriden formation are scarce, and fresh exposures non-existent.

A specimen collected 2.1 miles northeast of Northford (loc. 11) shows the rock to be a coarse-grained, pebbly, pale-pink arkose, locally almost conglomeratic, and weathering to a pinkish buff. The largest pebbles reach a diameter of 2 or 3 cm. A few bands of green and maroon, fine-grained, clayey sandstone (the so-called "shale") are present. They are only 5 to 8 cm. thick. The rock shows a rude banding which can almost be seen in a hand specimen. Sizing and sorting ap-

pear to be extremely poor, and this impression is confirmed by a mechanical analysis.

The rock is a typical arkose consisting of red and white feldspar, quartz, and, to a minor extent (5 to 6 per cent by actual count), fragments of a greenish gray, layered quartzite. There is no effervescence with cold HCl.

This lower arkose of the Meriden formation is overlain by an impure limestone, 15 feet thick at its type locality, in a quarry near Coe's Mill, on the New Haven-Durham highway just north of the Middlesex County line. The main body of limestone, exposed for a length of 750 feet in the quarry, has, furthermore, been traced in the field for approximately one-quarter mile south and more than 1 mile north. According to Percival (1842, p. 363), a limestone quarry now concealed, was formerly worked west of Paug's Pond. This would add at least another one and a half miles to the northern extension of the main limestone body. Percival says that at this locality the lower arkose is missing and the limestone rests directly over the lower lava flow ("amygdaloid"). A series of scattered outcrops, in places observed, and in places not visible at the present time, but mentioned as existing by Percival and Davis, suggest that this limestone extends almost to the outskirts of New Britain. Its thickness decreases northward, and in the New Britain region, in the outcrop at Shuttle Meadow reservoir, it is only 1 foot thick.

At its type locality (locs. 9 and 10), the limestone is a banded and layered bluish-gray rock passing into a micaceous silty sandstone at both top and bottom. The limestone proper is 13 feet thick. It is very irregularly jointed and banded (2 to 35 cm.). The fresh, dark or light grayish-bluish surface weathers to a yellowish-buff. Many very small (0.5 to 2 mm.) solution cavities can be seen everywhere. Clastic impurities are not easily seen in the fresh rock, but stand out prominently on weathered surfaces, and can be especially well observed after etching the rock with acid (Plate XIII-B). The impurities are then seen to consist either of isolated sand grains scattered throughout the rock or of minute lenses and small layers of sand, very irregular in shape, usually curved and contorted. This irregularity tends to mask the general banding of the limestone.

In addition to these minute, curved sandy layers, there are also more regular clayey and sandy bands parallel to the bedding plane. The most important of these, 10 feet above the base of the limestone, reaches a thickness of 6 cm. This band is composed of a number of fine curved laminae (0.25 to 1 mm. thick). These bands indicate periods of interruption in the deposition of the limestone. The cyclic character of the process is also confirmed by banding in the limestone itself, marked by changes in color and coarseness. All these limestone bands are somewhat irregular. The presence of desiccation breccia (?) has been mentioned by W. L. Russell, but none is exposed in the quarry at the present time. The limestone contains rounded bodies, apparently of organic origin, suggesting fresh-water algae (Charophyta, Plate XIV-A and B).

The limestone passess both at top and bottom into a fine-grained grayish-buff silty micaceous sandstone. The underlying sandstone is ripple-marked, with indication of a local eastward current. It is already quite rich in calcium carbonate (41 per cent), but the transition to the real blue limestone is, nevertheless, a well defined one. A detailed description of the members of the section is given in the chapter on Petrography.

The limestone is followed by a series of fossiliferous dark shales, poorly exposed in creek bottoms south of Durham. These shales are very similar to the section described at Shuttle Meadow reservoir. The dark beds are approximately 50 feet thick, and are overlain by yellowish and reddish siltstones and sandy shales and by pink arkoses, some of which are micaceous and platy to such an extent that at a distance they can be easily mistaken for shales. All these rocks are soft and nonresistant to erosion. As a result, there is a notable lack of exposures in the lower Meriden belt of southern Connecticut. These rocks are, in many places, injected by a complex system of diabasic dikes and sills, which are much more resistant to erosion and form a series of ridges that are developed best between Foxon and Totoket. A notable feature of the region is the presence of clastic sandstone dikes, which intrude trap sills. Several of these dikes, 1 foot thick, can be seen on the Foxon road, in a road cut on the top of a small ridge, 300 feet west of the North Branford town line. There is a micro-brecciated border, and under the microscope, the sandstone is seen to contain minute pieces of trap dragged from the neighboring sill. The sand grains near the wall of the dike are re-oriented, and are parallel to the border. Later movements refractured both sill and sandstone dike and formed fissures which are now filled with calcite (Plates X and XI).

Several good outcrops of arkose are found near the top of the series, close to the base of the middle lava sheet. A remarkable micaceous pink arkose, at places passing into a conglomerate, is exposed at the southwestern extremity of Totoket Mountain, near the quarry.

Lower division, uppermost arkoses and tuffs (?). The lower contact of the middle lava sheet is well exposed near the southern end of the trap quarry at Reed Gap on the Airline Railway (loc. 7). This excellent outcrop, not known to be duplicated anywhere else in Connecticut, shows 25 feet of sediments under the lava. The section consists of interbedded arkoses, shaly siltstones, and tuff-like rocks; it is discussed in the next chapter, together with the detailed petrography of the contact and the problematical tuff-like layers. It may be mentioned here that at this locality a gray arkose below the middle lava has been bleached by the thermal action of the lava, thus conclusively proving that the red color of the Triassic beds is of primary, pre-diagenetic origin. See Figure 15.

Upper division. The middle lava flow is overlain by a greenish-white feldspathic sandstone, which, upon weathering, assumes a peculiar spotted appearance (yellow spots). This particular spotted

weathering is typical of the upper Meriden feldspathic sandstones both in central and in southern Connecticut. The rock is indistinctly banded (2-3cm.). Near its very base this sandstone contains rounded pebbles of amydaloidal trap. Good outcrops are found on the western shore of Lake Gaillard (North Branford reservoir) The sandstone, at least 300 feet thick, passes into a red siliceous siltstone, and into dark shales and arkoses. The series (200 feet thick) was well exposed during the construction of the reservoir dam at Lake Gaillard,

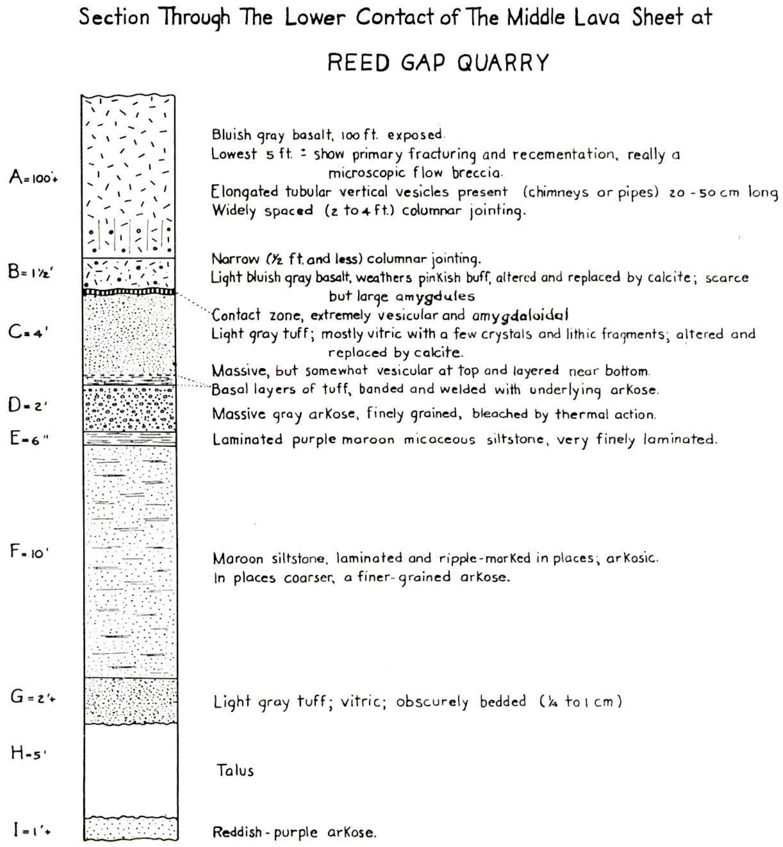


Figure 15. Stratigraphic section at Reed Gap Quarry (loc. 7) showing contact action on underlying sediments produced by heat and solutions radiating from the lower surface of the middle lava flow.

but is poorly visible now. It passes gradually into a complex series of black arkoses from Thorpe's section are described in detail in the next conglomerates. The series was measured and described by Thorpe (1928, pp. 281-283) during the construction of the Sugar Loaf tunnel in North Branford. Thorpe's section, 344 feet thick follows:

Section in the Sugar Loaf Tunnel

Top of the Posterior Series at the East Portal

Ft.	In.	
35		Shale and arkosic sandstone, reddish, coarser toward east. Dip 12° E. 8° S., strike N. 8° E.
4	6	Thin-bedded reddish shale.
14		More massive dark shales and conglomeratic sandstones.
3	6	Black shales, with occasional boulders.
4		Black shales, ripple-marked.
2		Coarse arkose with ripple-marks.
10		Thin to medium-bedded red and gray shales and sandstones. Slickensides on south wall, dip a little north of vertical.
8		Medium-grained gray arkosic sandstone.
2		Black shales.
11	7	Fine-grained arkose—homogeneous. Dip 15½° E. 10° S.
9		Heavy coarse conglomerate—iron stains prevalent in this horizon—not noticeable elsewhere in tunnel.
8	9	Dark-gray to black shale and sandstone—amorphous structure, with uneven fracture. Fossil wood plentiful. Horizon TH.
5	4	Grayish arkosic sandstone.
	14	Black shales.
5	7	Grayish arkose.
9	4	Fine-grained black shales. Dip 4° E. 20° S. **Eubrontes giganteus** footprints in ceiling. Shale very brittle. Horizon TG.
8		Medium conglomerate with inclusions up to 14 in. in diameter. Many quartzite boulders. Slickensides, south wall vertical, north wall dips 55° north.
6		Conglomerate. Slickenside, north wall, dipping 49° north.
2	2	Black shale interbedded with layers of gray arkosic sandstones with darker gray and reddish streaks. Slickensides, dipping 75½° N., 80½° N., and 64° S. Dip of shale 8° S., 10° E.
3	4	Medium conglomerate. Dip 6½° S.
2	3	Coarse conglomerate, becoming arkosic toward the east.
6	8	Fine to coarse conglomerate. Cross-bedding, arkosic, grayish and reddish streaks, irregular bedding. Inclusions of granite, chlorite schist, etc., up to 8 in. in diameter. Dip 6° S.
8		Coarse grayish conglomerate, with large greenish inclusions.
6		Massive-bedded, medium-grained arkose, becoming coarser toward the east. Dip 3½° S.
3		Thin-bedded reddish and grayish sandstones—coarser toward the east and then finer again.
5		Massive gray sandstone. Excellent east-west fault surfaces, also a north-south system admitting large quantities of water.
2	6	Massive grayish-brown arkosic sandstone. Cross-bedding.
3	8	Thin-bedded grayish sandstone. Layers 1-2 in. thick.
2	3	Massive reddish to grayish sandstone. Dip 70° S. 35° E.
10		Massive conglomerate, large masses of granite, feldspar and quartzite inclusions. Cross-bedded, somewhat coarser toward the east but variable. Dip 5° S. 10° E. Foot of Shaft A.
15		Arkose mostly thick-bedded, but with occasional thin-bedded layers grading to sandstone. Horizon TF. **Gigandipus caudatus,** No. 370; **Eubrontes approximatus**. No. 1146; **Anchisauripus exsertus**, No. 1214; **parallelus**, No. 1223; and **tuberosus**, Nos. 1210 1211, 1212, 1213, 1215.
5	8	Cross-bedded arkose, slightly conglomeratic in places.
7	1	Massive sandstone, with occasional thin-bedded layers. Dip 4° S. 45° E.

Ft.	In.	
8		Massive to thin-bedded medium-grained red sandstone. Dip 3° S. 45° E.
6		Massive jointed red sandstone. Joints trend a little south of east.
2		Fine-grained shaly red sandstone.
2		Medium-grained shaly sandstone, with dark-colored lenses.
3		Soft shaly sandstone.
4		Massive, medium-grained, cross-bedded sandstone. Dip 11° S. 70° E.
2	6	Massive, jointed sandstone.
2		Thin- to medium-bedded sandstone with greenish (chloritic) layers. Horizon TE. **Anchisauripus exsertus,** No. 362.
1	8	Cross-bedded sandstone, beds 6-8 in. thick.
6	1	Massive red sandstone.
1		Soft dark shales.
6		Fine- to medium-grained massive arkosic sandstone. Dip 1° S. 40° E.
2		Massive, coarse-grained sandstone.
5	6	Medium-grained sandstone, occasionally thin-bedded, but mostly massive. Dip 10½° S. 30° E.
3		Thin-bedded sandstone. Dip 9° S. 30° E.
5		Massive sandstone, 3 layers, some cross-bedding.
1	6	Dark shale.
2	4	Massive, medium-grained red sandstone.
	4	Thin, shaly sandstone.
5	6	Somewhat finer grained coarse-bedded sandstone.
1	9	Coarse-grained red sandstone.
3	7	Massive coarse-grained sandstone. Dip 4° S. 15° E.
3		Thin- to thick-bedded sandstone with fine- to coarse-grained lenticular inclusions.
6		Massive-bedded sandstone, fine-grained, conchoidal fracture. E-W joint or fault planes, admitting large volume of water.
5		Very fine-grained papery shales and thin-bedded red sandstones. Horizon TD. **Triaenopus lulli,** Nos. 1217 and 1225; **Anchisauripus hitchcocki.** No. 1222.
	8	Massive, medium-grained red sandstone with coarse mud-cracks, Horizon TC. **Batrachopus deweyi,** No. 1218, probably from here.
4	6	Very thin dark-gray micaceous shales. Horizon TB. **Eubrontes giganteus,** No. 373; **Shepardia palmipes.** No. 368; **Anchisauripus exsertus,** Nos. 367 and 1140, and **sillimani,** Nos. 369, 1139, 1220.
1	2	Gray sandstone.
6	7	Thin-bedded dark micaceous sandstone, beds not over 3 in. thick, lens structure locally developed.
12	5½	Massive tough gray sandstone. Dip 10½° S. 15° E. Many tracks and fossil wood. Horizon TA. **Grallator formosus,** No. 375; **Eubrontes approximatus,** Nos. 371, 1144, 1145; **Anchisauripus exsertus,** Nos. 361, 363, 372, 374, 1216; **exsertus branfordi.** No. 360; **parallelus,** Nos. 1137, 1221, 1223, and **tuberosus,** No. 1142. Bottom of this series at West Portal.
344 ft.	5½ in.	Total.

An examination of this section shows that the material near the top and also near the eastern part of the section, close to the Great Fault, is very coarse, with boulders 14 inches in diameter present. This is the transition zone between the normal and the Great Fault facies of the Meriden formation. Some remarkable footprint-bearing

black arkoses from Thorpe's section are descbired in detail in the next chapter. The top of the section differs vastly according to its geographic location. At Lake Quonnipaug, where the Portland formation is faulted out, and the upper Meriden beds are exposed at the surface along the fault, they consist of typical fanglomerates. East of Lake Saltonstall, one and a quarter miles west of the fault, the uppermost Meriden beds, under the upper lava sheet, are extremely fine-grained, brick-red, fissile shales ("paper shales").

Portland Arkose

General Features

Distribution. The Portland arkose (the "Eastern Sandstone" of Percival) covers the eastern part of the Connecticut Valley. It is developed extensively in central and northern Connecticut, but has been almost entirely faulted out in southern Connecticut, and is practically absent in the vicinity of New Haven. The best exposures are found near Middletown in the Portland "brownstone" quarries.

Along the Great Fault the Portland formation is represented by fanglomerates which are exposed in a series of excellent outcrops from New Haven to the end of the Triassic basin at Northfield, Mass. Among the best exposures are that of Durham, at the intersection of routes 15 and 77, that of Lake Quonnipaug, and that at locality 20, in East Portland, one-quarter mile south of the intersection of route 15 and the Gildersleeve road.

Thickness. The top of the Portland arkose has been eroded away. The present thickness left by erosion has been estimated to reach 4,000 feet in central Connecticut. The original thickness may have been much greater.

Character. The Portland arkose consists of conglomerates, reddish-brown and purple arkoses (some are grayish), fine-grained micaceous siltstones, and subordinate red and dark shales. The material becomes coarser from west to east, and in the vicinity of the Great Fault the formation is represented by coarse conglomerates and fanglomerates.

In the normal facies of the formation conglomerates form 13 per cent, arkoses and sandstones 57 per cent, siltstones 23 per cent, and shales 7 per cent.

Mineral horizons. It is possible to divide the Portland formation in central Connecticut into two mineral zones, each approximately 2,000 feet thick. The lower zone is characterized by a high garnet content (56 per cent), a low ratio of pink to colorless garnet (3 per cent), and a high amount of tourmaline (33 per cent). The upper zone contains a very high percentage of garnet (72 per cent), a relatively high ratio of pink to colorless garnet (20 per cent), and a lower amount of tourmaline (14 per cent).

This difference in mineral composition, however, is not well reflected in the general lithology and field appearance of the formation.

Normal Sedimentary Facies, Central Connecticut

The normal facies of the Portland arkose have been preserved only in central Connecticut, having been obliterated by faulting and erosion in southern Connecticut.

These normal facies consist of a succession of reddish, pinkish, grayish, maroon, and deep-purple beds, lithologically rather similar to the New Haven arkose, except that as a whole they are much redder (63 per cent of red beds in the Portland formation as against 45 per cent in the New Haven arkose). The lower part of the formation is in general relatively fine-grained (siltstones and fine red feldspathic sandstones). Subordinate beds of dark shales and feldspathic sandstones are present west of the Durham meadows.

As the top of the section is approached, the gross lithology gradually changes, with coarser arkoses and conglomerates predominating. Inasmuch as this change also necessarily takes place from west to east, it it possible to interpret the increasing coarseness as due to geographic rather than to stratigraphic causes. Fragments of Bolton schist and large mica flakes are extremely common at all levels of the Middletown formation.

The brownstones quarries of Portland (Plate XXII-B) provide a series of good outcrops illustrating all the lithologic variations from micaceous siltstones to medium-sized conglomerates. These quarries have been described in detail by Rice and Foye (1927, p. 57). They have yielded numerous animal footprints and fossil tree trunks (logs). Mud cracks and ripple marks appear to be more abundant here than at any other place in the Triassic section, but this may be because quarrying has exposed many horizontal surfaces which are usually not visible in the ordinary two-dimensional outcrop.

The Portland brownstone proper may contain locally a considerable amount of rock fragments (up to 30 per cent of Bolton schist quartzite and gneiss fragments). Small iron-oxide concretions of primary origin are found in some of the layers (Plates XIX-A and XXIX-F). Their climatic significance is discussed later.

The dip at Portland is very low, the strata being almost horizontal, presumably as a result of local warping, or a retrogressive movement along the Great Fault.

Great Fault Fanglomeratic Facies

In the immediate vicinity of the Great Fault the Portland formation is represented by fanglomerates which are in no way different from the older Meriden fanglomerates. These fanglomerates are described in the chapter on Petrography. The lower Portland fanglomerates immediately above the upper lava flow contain at North Branford large basaltic boulders, thus indicating a certain extension of the upper lava flow east of the Great Fault.

CHAPTER IV

PETROGRAPHY

Regional Petrology

The relatively soft Triassic sediments underlie a valley carved between two highlands made up of resistant crystalline rocks. These Paleozoic crystallines consist of schists intruded and injected by large masses of granite and granite gneiss.

In the Eastern Highland silicic igeneous rocks predominate over the older schists. Within 10 miles east of the Great Fault there is only one important schistose body: the Bolton schist which outcrops in a narrow belt immediately east of the Great Fault. On the other hand the following large granitic masses are present in the same region: Stony Creek and Lighthouse Point granite; Branford, Maromas, Glastonbury, and Haddam (or "Killingworth") granite-gneisses.

In the Western Highland the reverse is true: Large masses of schists of various metamorphicrank (from phyllite and chlorite-schist to high rank mica-schists) are intruded or injected in a much smaller scale by bodies of gneiss (the Prospect gneiss). The largest and most important of these older schists is the Hartland schist, which is seen to underlie the Triassic at Roaring Brook.

Thus, in a general way, the Eastern Highland is an acid (silicic) igneous province, whereas the Western Highland is a metamorphic one.

With the exception of the Bolton schist which occurs either in a chloritic and phyllitic (green) or a quartzitic (grayish) facies, the rocks of the Eastern Highland consist of coarse, pink or gray, granites and granite gneisses with a great amount of pefmatites. These rocks are made up of quartz, microcline, albite, sodic-oligoclase, and, in much smaller amounts, of orthoclase and andesine.

The Triassic sedimentary rocks have been derived *exclusively* from the granitic (and subordinate schistose) rocks of the Eastern Highland. Pebbles and heavy minerals from the Triassic sediments can be matched with identical material from the source area east of the Fault. Particularly striking examples can be made in the case of the Bolton schist and especially the Stony Creek granite. Pink granite pebbles showing a typical graphic intergrowth and recognizable, large, smoky, frequently zoned zircons can be traced from the upper New Haven beds to the Stony Creek granite.

General Character of the Triassic Rocks

Distribution of Lithologic Types

The Triassic sediments of the Connecticut Valley consist of a mixture of arkosic sandstones and conglomerates, siltstones, red and black shales, and very subordinate limestones. The generalized gross

lithology of the Newark section has been presented in Table 3 and is summarized graphically in Figure 16. An additional breakdown of lithologic types into red and non-red (pale grayish-purple or black)

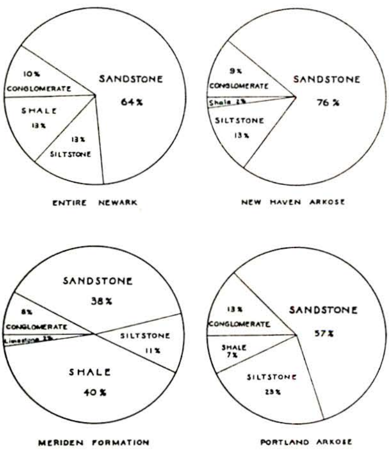


Fig. 16

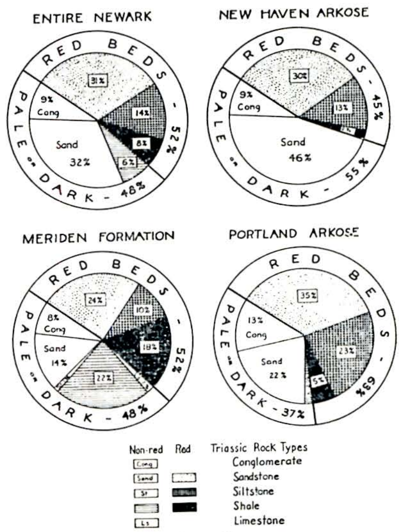


Fig. 17

Figure 16. Distribution of the principal (normal) rock types of the Connecticut Newark.

Figure 17. Distribution of Triassic lithologic types, showing relative abundance of red beds vs. non-red material in entire section and within each specific rock type.

varieties gives the following distribution as shown on Table II, which is also graphically presented in Figure 17.

TABLE 11

LITHOLOGY OF TRIASSIC ROCKS ACCORDING TO COLOR

	Total Newark	New Haven arkose	Meriden formation	Portland formation
Conglomerates	9%+	9%	8%	13%
Pale sandstones	32%	46%	14%	22%
Red sandstones	31%	30%	24%	35%
Red siltstones	14%	13%	10%	23%
Red shales	8%	2%	18%	5%
Black shales and siltstones ..	6%	—	23%	2%
Limestones	1%	—	2%	—

A somewhat different and more detailed estimated petrographic breakdown of the Newark section according to different sandstone, siltstone, and shale types is shown in Table 12.

Table 12 has been computed on the basis of an additional correction of Table II, based on the fact that the so-called pale sandstones of the preceding table (as seen in the field) are generally a mixture of petrographically distinct "pale arkoses" and "red arkoses" as described later under Composition. This pale sandstone mixture contains 75 per cent of "pale arkoses" and about 25 per cent of "red arkoses".

TABLE 12

DETAILED GROSS PETROGRAPHY OF THE TRIASSIC

Pale conglomerates	9.3%
Pale normal arkoses	16.3%
Red normal arkoses	20.0%
Faulted pale arkoses	2.1%
Faulted red arkoses	5.2%
Red feldspathic sandstones (Redstones)	18.3%
Pale feldspathic sandstones	2.1%
Red siltstones	11.2%
Red shales	8.0%
Dark siltstones	1.2%
Black shales	4.8%
Limestones	1.1%

Also, the "red sandstones" are made up of approximately 50 per cent of red arkoses and 50 per cent of "Redstone" with traces of pale arkoses. Fianlly, the red siltstones can be broken up into 80 per cent of real siltstones and about 20 per cent of Redstone, whereas the black shales contain about 20 per cent of dark silty beds.

Basic Make-Up and End Members

All the different lithologic types mentioned above are produced through the mechanical mixing, in all possible proportions, of *three* petrographic (and textural) end members:

1) A coarse-grained (sandy or pebbly) arkosic, i.e., modified granitic, detritus that has essentially the following average mineral composition:

Quartz		58%
Feldspar		40%
Microcline	79%	
Plagioclase	21%	
Micas		2%±

2) A fine-grained detrital clayey matrix consisting of "clay", either colorless or in most cases stained a very dark red color by hematite or in some cases, black by organic matter. This clayey matrix has the following average mineral composition:

Kaolin	60%—
Gibbsite	6%+
Sericite-illite-paste	12%±
Hematite	20%+

And in addition up to 20 or 30% of fine-grained quartz and feldspar.

3) A chemical carbonate cement, generally calcite.

Mechanical mixtures of these three end members are responsible for the different Triassic rock types. The predominance at any one locality of one or the other of these three petrographic end members depends again upon *three genetic factors*, all of them connected with the structural history and the overall topography of the Newark at the moment of sedimentation of a given member, i.e., whether the Great Fault-Scarp was active or not.

These controlling structural factors operate by modifying:

(a) provenance, i.e., the available type of detritus;

(b) deposition, i.e., type of detritus locally deposited as against type of by-passed detritus and local modification of deposited detritus; and

(c) diagenesis, i.e., type and amount of intrastratal introduction of chemical matter.

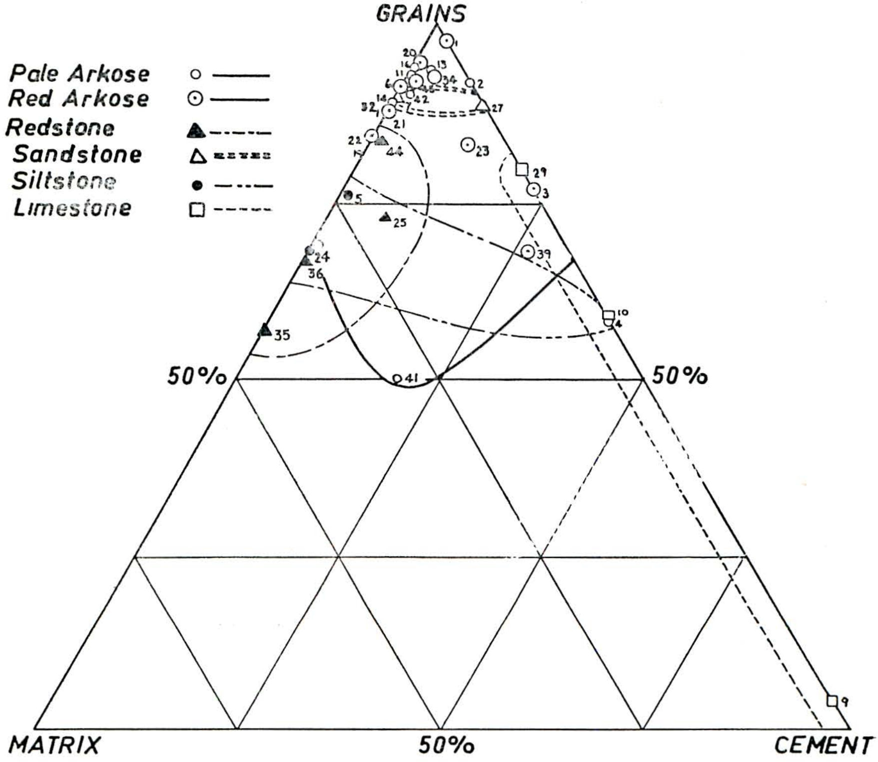


Figure 18. Distribution of the textural data presented in Table 4 according to major textural elements: grains, matrix, and cement. Numbers indicate localities; symbols, the lithologic type found at each locality; and the different lines outline the field of occurrence of each principal lithologic type.

As a rule, certain horizons of the Newark are characterized by the predominance of coarse or very coarse granitic detritus, resulting in the formation of conglomerates and arkoses. These represent periods related to a strong activity of the Great Fault (New Haven time).

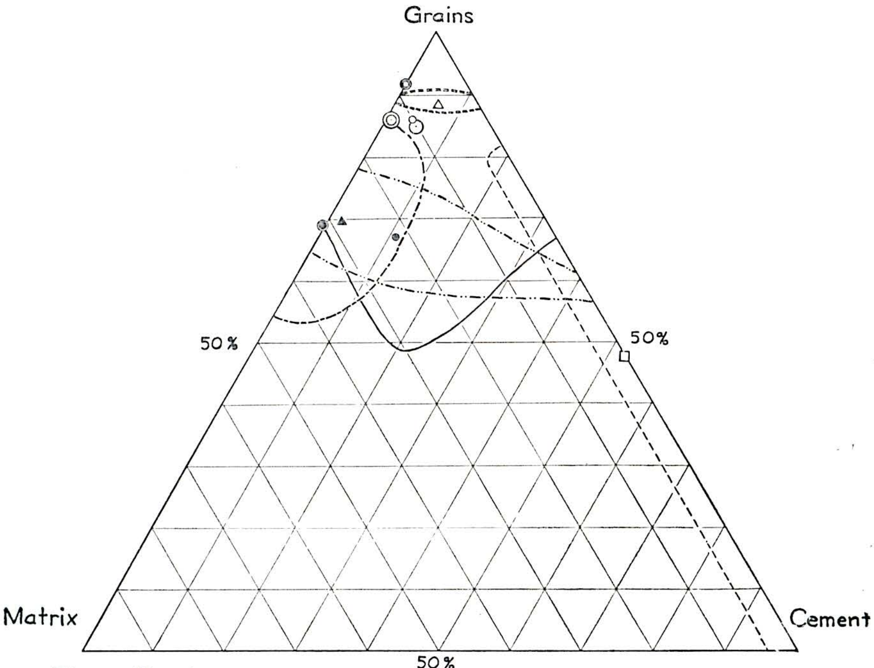


Figure 19. Average overall composition of the main Triassic rock types: two averages are given for each arkose (pale and red) and also for the siltstone-shale. One shows the mean total average of all samples, and the other gives the average for all samples not in the immediate vicinity of major faults. Numbers in parentheses after symbols indicate number of specimens of each type.

	Average of all samples	Samples away from fault
Pale arkose	(15)	(7)
Red arkose	(8)	(6)
Redstone	(4)	
Feldspathic sandstone	(2)	
Siltstone-shale	(6)	(4)
Limestone	(3)	

Other horizons (Meriden) are characterized by a predominance of the clayey type of detritus and are related to periods of relative quiescence of the Great Fault. Finally, other periods show intermediate tendencies (Portland time).

Within these basic limits, imposed by overall provenance, strong and marked local changes of a textural nature, due to changing environmental conditions, may also take place. The most typical contrast within the Triassic is between channel deposits characterized by the deposition of granitic detritus (and the bypassing of clayey detritus) as against flood-plain deposits, characterized by the precipitation of the clayey detritus and the non-arrival of the granitic detritus (left largely behind within the channels). Under lacustrine conditions of very slow current velocity and stagnation, an even more complete differentiation takes place between the granitic detritus, now restricted to the alluvial fans and deltas, and the clayey detritus which forms the bulk of the lacustrine shales. A last step in this stagnation phase leads to the reduction of the hematitic clay and the formation of the black shales and limestones through the introduction of a depositional chemical factor.

During the post-diagenetic and intrastratal phases, circulating solutions may load some of the sediments with calcite cement. This again happens to be a function of structural activity, since most of the calcite cement within arkoses is found in the immediate vicinity of large faults.

The relationships between grains (i.e., granitic detritus), matrix (i.e., clayey detritus, generally hematitic), and cement (i.e., calcite) are shown in Figure 18 (plotting of all localities) and Figure 19 (condensed plotting of lithologic types).

These ratios are itemized in Table 4A and are summarized in Table 13.

Megascopically these relationships between end members manifest themselves in two ways:

1) through the grain size (texture).

2) through the color (red or non-red) and general appearance, i.e., composition.

TABLE 13

BASIC MAKE-UP OF TRIASSIC ROCK TYPES

	Granitic detritus	Clayey detritus	Calcite
Normal pale arkoses	90%	9%+	X
Normal red arkoses	92%	7%	X
Faulted arkoses	77%	5%	18%
Redstone	73%	27%	X
Pale feldspathic sandstone	93%	X	7%
Shales and siltstones	64%	34%	2%
Limestones	39%	X	57%+

Texture

Definition of Terms

The Triassic of Connecticut is made up of conglomerates, sandstones, and shales of different colors and degree of rounding.

Inasmuch as the terms "arkose" and "shale" have been often used loosely in the past when describing the Triassic sediments, the following definitions are given cncerning the terms used in describing the megascopic gross lithology of the Newark as shown in Table 3 and elsewhere in the text:

Conglomerate: A rock consisting of at least 50 per cent of pebbles over 1 cm. in diameter.

Sandstone (and arkose): Any rock intermediate between a conglomerate and a siltstone. The term "pebbly or conglomeratic sandstone" applies to a sandstone having more than 10 or 20 per cent of pebbles respectively, and the term silty or clayey sandstone (and this includes the "Redstone") applies to a sandstone having more than 20 per cent of silt or clay. Sandstones are broken into several mineral types and subtypes.

Siltstone: A fine-grained gritty rock composed of particles 0.1 mm. in diameter or less.

Shale: A non-gritty, finely laminated clayey rock. A very high percentage of the so-called Triassic "shales" are in reality fine-grained sandstones high in clay (so-called "Redstone").

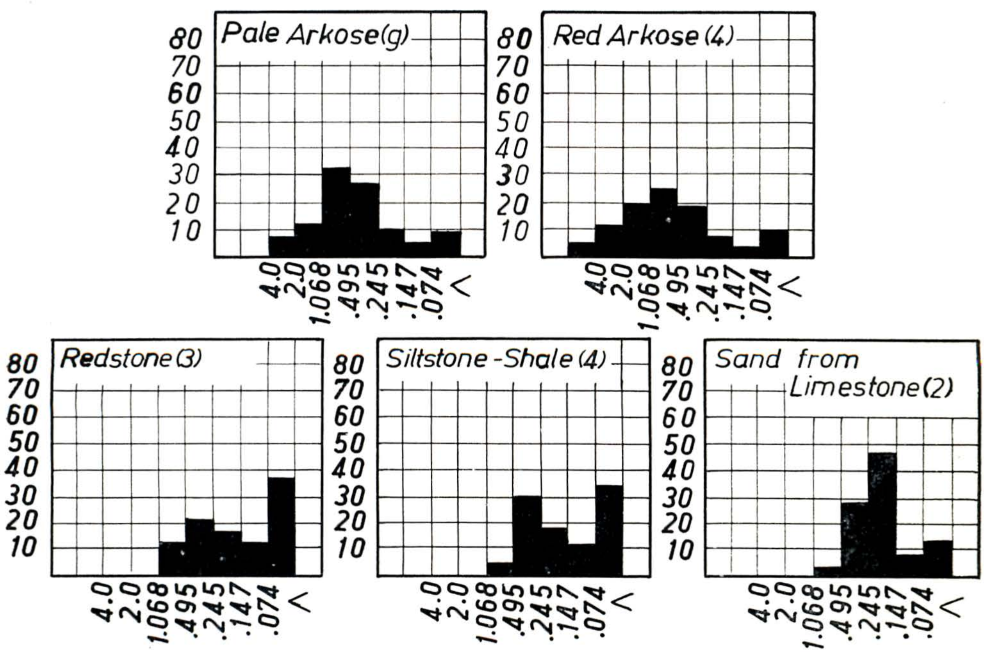


Figure 20. Average of mechanical analyses of the principal Triassic lithologic types. Numbers in parentheses indicate how many analyses of each type were used for the average. See Table 4 for actual data.

Color and the amount of clayey material present are two factors, which although ultimately depending upon composition, nevertheless are to a large extent textural features, since they represent the ratios between coarser and finer material. On the basis of these two factors it is possible to divide the sandstones of the Newark into relatively coarse-grained arkoses and relatively fine-grained feldspathic sandstones. The arkoses can be divided into pale and red varieties and the feldspathic sandstones also into pale and brick-red varieties, the latter type or "Redstone" being very high in clay (about 25-30 per cent).

Thus the sandstones fall into four additional tpyes, namely:

1) Pale arkoses
2) Red arkoses
3) White, non-clayey, feldspathic sandstones
4) Brick-red, *clayey*, feldspathic sandstones or "*Redstone*".

These four types are defined and discussed in some detail farther along in this chapter.

Grade Size Distribution

As a whole, the Triassic section is extremely coarse-grained. It contains 64 per cent of sandstones and close to 10 per cent of conglomerates, or a total of 73 per cent coarse clastic rocks as against

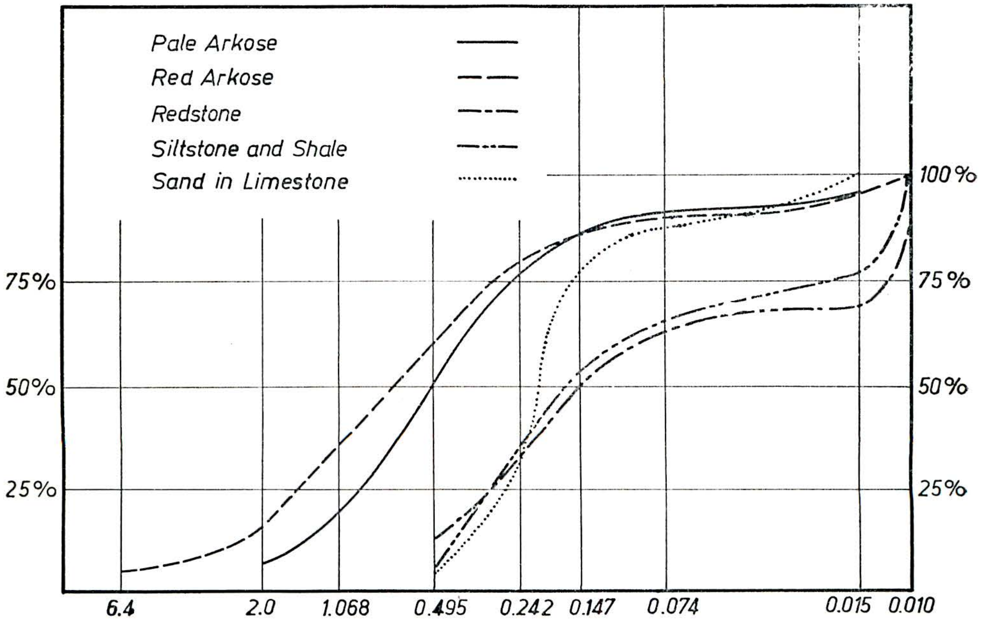


Figure 21. Cumulative curves of averaged grade-size distribution of the same principal rock types presented as histograms in Figure 20.

only 40 per cent of sandstones and conglomerates found within the average stratigraphic section throughout the world.

Furthermore, the sandstones themselves tend to be coarse-grained. The average median diameters of the main Newark lithologic types are as follows:

Pale arkoses	0.546 mm.
Red arkoses	0.725 mm.
Redstone	0.140 mm.
Siltstones	0.174 mm. (—)
Shales	0.055 mm. (±)
Sand in limestone	0.177 mm.

These diameters again are much higher than those of the average sandstone[5].

Composite histograms and cumulative curves of mechanical analysis averaged from Table 4A are shown on Figures 20 and 21.

There is considerable overlapping of the median diameters between the white feldspathic sandstones, the red clayey feldspathic sandstones ("Redstone"), and some of the red siltstones. The megascopic differences between the appearance of these types, however, are marked.

Sorting

The ssorting (i.e., mechanical sorting or sizing) of the Triassic sediments as a whole is very poor.

Sorting coefficients of the principal Newark rock types, as averaged from Table 4A are as following:

Pale arkoses	1.836
Red arkoses	2.235
Redstone	5.21
Siltstones and shales	4.115
Sand in limestone	1.337

The somewhat obscure (parabolic) relationship between median diameter and sorting coefficient is presented graphically on Figure 22.

As seen from the averaged histogram of Figure 20, all Triassic clastic rock types show a secondary maximum in the finest grade size (clay). This is the result, first, of the very nature of the parent material, namely, a heterogeneous mechanical mixture of very coarse and very fine detritus and, second, of the relatively inefficient—or rather ineffective—sorting process that operated during Newark sedimentation.

As can be readily seen in the field, Triassic sedimentation was a one-cycle affair with rapid burial of the sediment after very rapid

[5] P. D. Krynine, unpublished data.

deposition and hardly any reworking of the precipiated detritus, thus cutting down the time available for reworking almost to nothing.

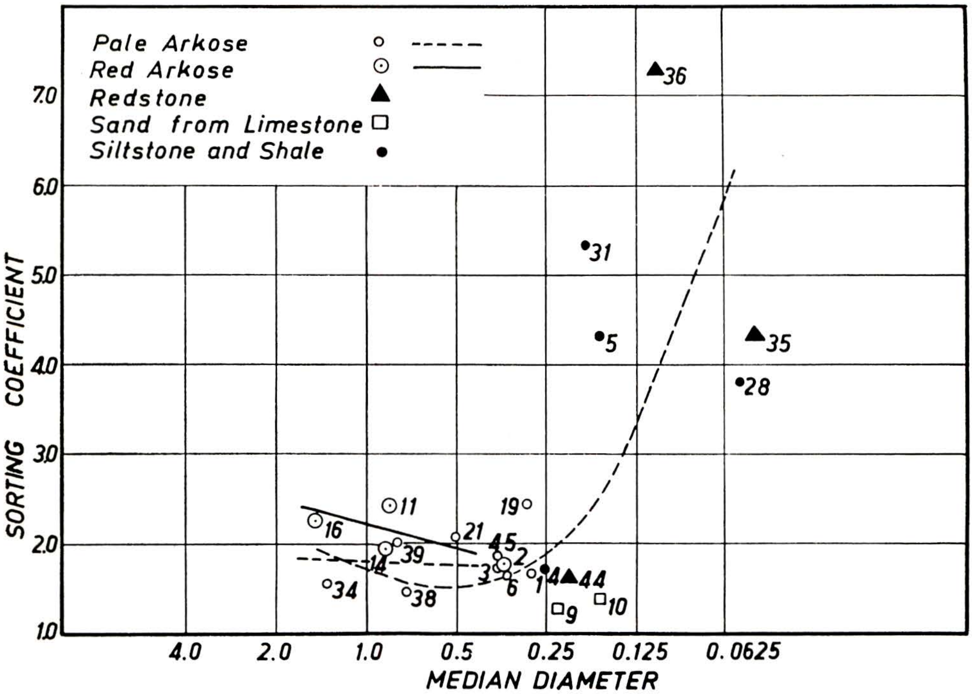


Figure 22. Relation between median diameter and sorting coefficient within the principal Triassic rock types. Numbers indicate localities. Distribution follows a straight line for pale and red arkoses but approximates an inclined parabola for overall average.

In the very few instances where the time element and opportunity for reworking were increased, as in the lacustrine beds of the Meriden, the sorting of the sand is more pronounced, at places definitely so. This improved sorting goes hand in hand with a considerable increase in rounding.

Angularity

Practically all the Newark detritus is very angular to begin with, and the rapid and violent erosion and deposition processes of Triassic time did very little to decrease this angularity.

A quantitative study of angularity can proceed with great precision along the mathematical pattern of Wadell's measurements of the inscribed and circumscribing circles or can be done much more rapidly, albeit less precisely, by comparing the sand grains against certain arbitrary standards and yardsticks of roundness.[6]

The setting up of these standards and yardsticks is a somewhat subjective procedure of a highly pragmatic type, since, depending upon the character of the sediment, the emphasis on identification and splitting of types may shift from the angular to the well rounded end.

The following scheme of standards, with emphasis on the angular end, can be applied successfully in the Connecticut Triassic:

1) **Very angular**—the grains are broken into a series of irregular, jagged splinters with razor-like edges. All fractures are perfectly fresh.

2) **Angular**—the grains are either idiomorphic or xenomorphic but are as a rule in one piece (not broken into splinters). All fractures are perfectly fresh. All edges are sharp with no evidence of blunting whatever.

3) **Subangular**—at least one edge is definitely rounded but not over 50 percent of the edges show much rounding. All other edges are either fresh or sharp or show some very small blunting. The grain still retains its original shape.

4) **Subrounded**—all edges are definitely rounded and at least 50 per cent of them show perfect curvature. There are no sharp edges whatever. The grain still has a general outline reminiscent of its original form. Rounded embayments rather than approach to sphericity are the rule.

5) **Rounded**—the grain approaches sphericity, the original primary shape having been obliterated in the meantime. All edges are completely smooth.

To compare the rounding of different specimens, it may be desirable to reduce the obtained frequencies to a numerical coefficient. In order to do this, the following values have been assigned to the different degrees of rounding:

Very angular	0
Angular	25
Subangular	50
Subrounded	75
Rounded	100

[6] "Roundness", or rather "rounding", properly refers to the smoothness of the edges, i.e., is essentially a measure of abrasion or wear, whereas "sphericity" refers to the tendency of an object to approach an equidimensional shape. A cube has much greater sphericity than an elongated ovoid, but is much less rounded.

In highly angular first-cycle sediments of the Newark type a certain confusion between rounding and sphericity is almost unavoidable, when doing comparison work against yardsticks of angularity. In such types of sediments "rounding" is probably a more diagnostic criterion than sphericity, although, in other types of sediments the reverse is more commonly true.

By multiplying these coefficients by their respective percentages and adding them, the obtained total will be the general rounding coefficient of the whole sample. For instance, a sand containing 20 per cent of angular grains, 40 per cent of subangular, 35 percent of subrounded, and 5 per cent of rounded grains will have a rounding coefficient of 57.

A brief quantitative study of three typical Triassic rocks—a coarse fluvial red arkose and two lacustrine sands that form the insoluble sandy fraction of two Meriden limestones—is presented in Table 14.

This study shows that feldspar consistently shows more rounding than the quartz, regardless of the fact that there does not seem to be such primary difference in shape within the parent igneous rock and, second, that under lacustrine conditions (even in shallow and rela-

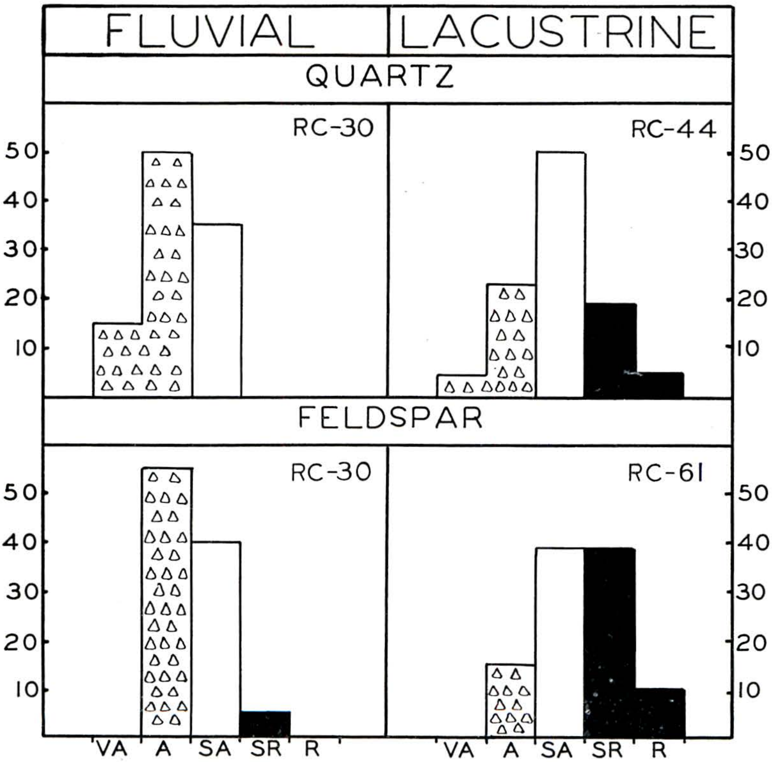


Figure 23. Comparative rounding of quartz and feldspar under different conditions of lacustrine and fluvial deposition. R C is the rounding coefficient; VA - very angular; A - angular; SA - subangular; SR - subrounded; R - rounded.

tively short-lived lakes) a much better degree of rounding is achieved than under fluvial conditions. This is particularly noteworthy considering that the lacustrine sands are much finer-grained than the fluvial specimen, and, as generally known, coarse sand has a tendency to show better rounding than finer-grained sand.

A preliminary inspection of normal fluvial sediments from east to west seems to show that the degree of rounding of both quartz and feldspar increases with the distance of transport within the Triassic. However, no quantitative work has been done on this phase of the problem as yet.

An interesting feature is the remarkable degree of rounding of the micas in the lacustrine beds. Muscovite flakes may assume an almost perfectly rounded coin-like shape (Plate V-B). Similar rounding of the micas has been observed by the writer in the Pleistocene-glacial lake deposits of Connecticut.

TABLE 14

COMPARATIVE ROUNDING OF TRIASSIC FLUVIAL AND LACUSTRINE SEDIMENTS

	Fluvial deposit Red arkose Loc. 15 (0.58 mm.)		Lacustrine deposits Sand in limestone Loc. 10 (0.177 mm.)		Loc. 31 (0.183 mm.)		
Median Diam.	Quartz	Feldsp.	Quartz	Feldsp.	Quartz	Feldsp.	Muscovite
Very angular ...	15%	—	—	—	8%	—	—
Angular	50%	55%	15%	10%	30%	20%	—
Subangular	35%	40%	50%	35%	50%	40%	—
Subrounded	—	5%	25%	40%	12%	35%	20%
Rounded	—	—	10%	15%	—	5%	80%
Rounding coefficient	30	38	48	65	41	57	95

Composition

Major Constituents

The different ratios between granitic detritus, clayey detritus, and chemically precipitated calcite account for the different rock types of the Triassic and the changes in their respective mineral compositions. Translated into specific mineral frequencies, the composition of the different rock types of the Newark section is given in Table 15.

Detrital minerals. Although the granitic detritus has an average composition of 58 per cent quartz, 40 per cent feldspar and 2 per cent mica, nevertheless these figures fluctuate somewhat within the different rock types. These changes in the mineral composition of the coarser-grained, meaning the sandy and silty, fractions of the rock (i.e., essentially within the granitic detritus) are shown in Table 16.

The composition of the clayey detrital fraction is not constant either. There are considerable changes in the ratios between hematite and the "white clay" minerals. These ratios are variable in different parts of the Newark section and may depart widely from the average of 60 per cent kaolin, 6 per cent gibbsite, 12 per cent sericite-illite, and

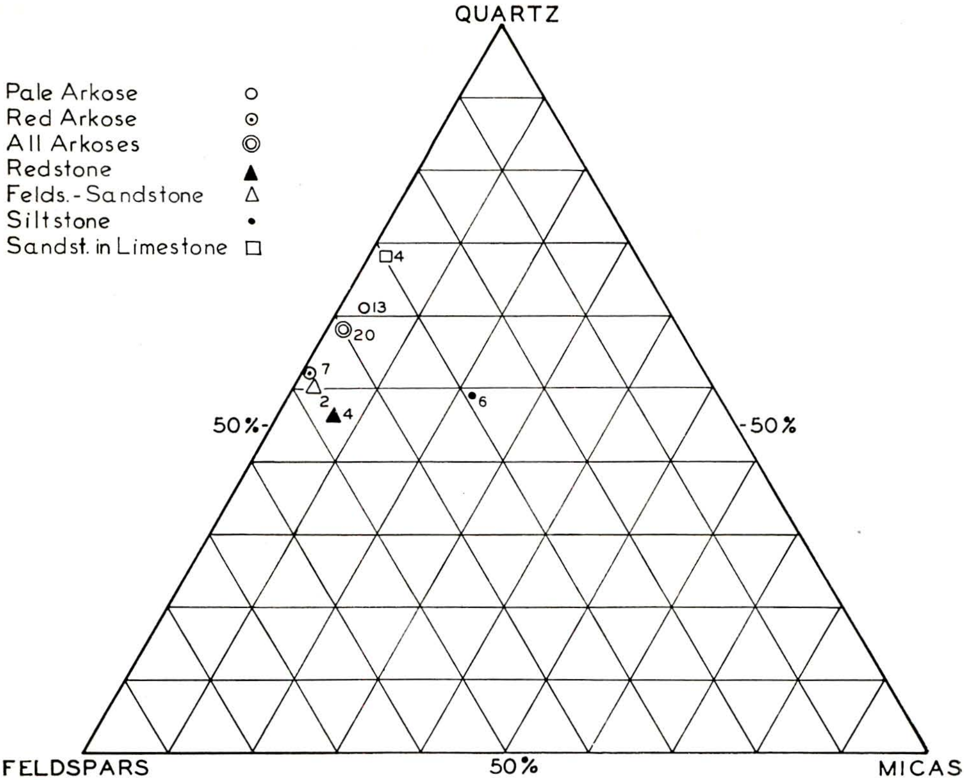


Figure 24. Average mineral composition of the sandy and silty fraction (i.e., grains only, excluding clayey matrix and cement) of the major Triassic rock types. Figures indicate number of analyses used. See Table 4B for detailed data. This illustration shows essentially variations within the granitic (arkosic) detritus.

20 per cent hematite. A quantitative evaluation of these changes would require the use of X-ray and differential thermal analysis methods on a scale that could not be used during the present work.

Chemical minerals. The calcite present in the Triassic has two distinct modes of occurrence:

1) As a chemical depositional precipitate in the lake and swamp beds of the Meriden formation, either as solid limestone layers, or as an important primary constituent of the lacustrine shales.

2) As a cement within the arkoses, being in this case a chemical precipitate of late, post-diagenetic, intrastratal origin. As shown in Tables 15 and 17 and Figures 18, 19, and 25, the occurance of such calcite cement is definitely related—and almost entirely restricted—to the very close vicinity (within 300 feet and generally much less) of large faults.

It is possible, or even probable, that the circulating solutions responsible for this late authigenic, intrastratal calcite were of late magmatic origin, representing the final, calcite phase of basaltic volcanism.

There are also some very restricted zones of silicate authigenesis within the Triassic which resulted in the formation of secondary overgrowths on some quartz, microcline, and albite grains. The distribution, both of calcite and of the authigenic silicates, is shown in Table 17.

It will be seen that these authigenic silicates either occur immediately below the lava flows (within 10 feet or less below the lava contact) or again are related, just like the calcite, to major faulting or, finally, may be found in very small amounts within the lacustrine bed, i.e., within a locus of normal primary chemical deposition.

In the entire Triassic section there is no evidence that intrastratal authigenesis—and intrastratal solution for that matter—ever operated on any sizable scale—if at all—within the normal sediments outside of the channel of large-scale fluid circulation that brought in the late magmatic solutions of the dying phase of the basaltic eruptions. This is also true, as shown later, for the occurrence of barite.

TABLE 15

MINERAL COMPOSITION OF THE TRIASSIC ROCK TYPES

	Quartz	Microcline	Plagioclase	Micas	Hematitic clay	White clay	Calcite	Others
Pale arkoses	57	24	6	3	3	6	X	1
Pale arkoses near fault	42	24	13	3	X	1	17	..
Red arkoses	51	30	11	1	7	..	X	..
Red arkoses near fault	34	32	5	1	8	..	19	..
Redstone	37	10	18	8	27	..	X	..
White feldspathic sandstones	47	17	26	2	..	..	..	..
Red siltstones and shales	34	14	9	11	30	..	2	..
Dark shales	30	10	17	12	..	34	2	5*
Limestones	25	10	3	1+	..	1+	58	5*
Weighted average for entire section**	44½	20	10½	5	13½	3½	2½	1.
Mean average of all samples**	45	21	10	4	9	2	8	1

X—Traces, less than 1 per cent.
*—Includes organic matter, barite, siderite, etc.
**—These frequences are shown in Fig. 3.

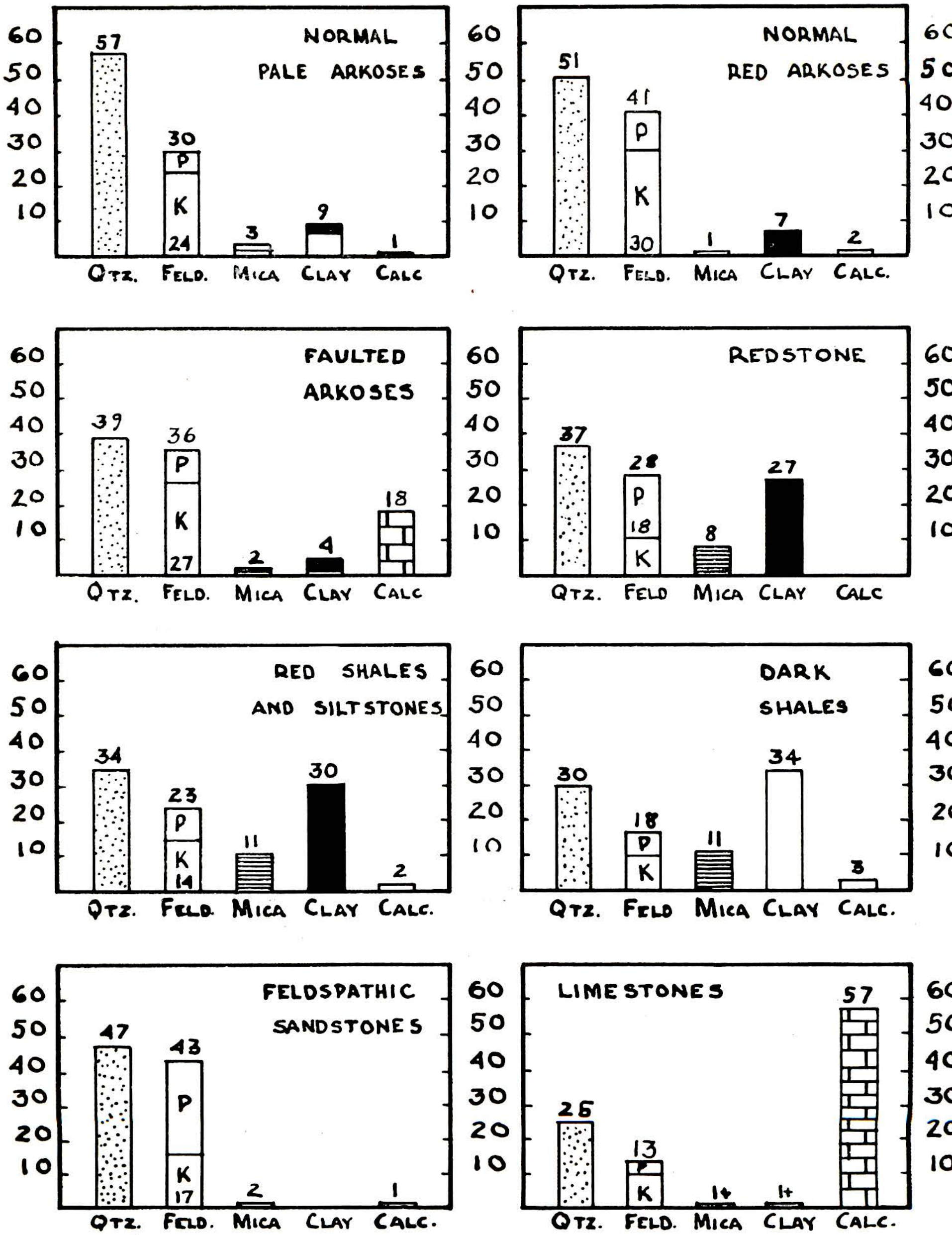


Figure 25. Total average mineral composition of the major Triassic rock types. In the feldspar, K and P indicate ratio of potassium feldspar (microcline) to plagioclase; hematitic clay is in solid black and unstained clay is in white. Numbers above feldspar column indicates total feldspar, numbers below indicate percentage of microcline.

TABLE 16
COMPOSITION OF SANDY ARKOSIC (GRANITIC) DETRITUS OF THE TRIASSIC ROCK TYPES

	Quartz	Feldspar	Micas	K-Feldspar: :Plagioclase ratio
Pale arkoses	61	36	2	80:20
Red arkoses	52	47	1+	77:23
All arkoses	58	40	2+	79:21
Redstone	46	47	7+	40:60
White feldspathic sandstones	51	47	2	40:60
Siltstones and shales	49	29	22	66:34
Sand in limestones	68	30	2	75:25
Average	58	40	2	75:25

TABLE 17
DISTRIBUTION OF CHEMICAL AND AUTHIGENIC MINERALS OF THE TRIASSIC SHOWING BREAKDOWN OF OCCURRENCES BY TYPES OF ENCLOSING DEPOSITS

Distribution of occurrences by per cent among the following types of deposits:	Calcite	Authigenic (secondary) silicates		
		Quartz	Microcline	Albite
Lacustrine and paludal.........	31%	20%±	—	25%±
Near large faults	48%	45%±	75%±	25%±
Below lava flows	7%	35%±	25%±	50%±
Normal unfaulted fluvial	14%	—	—	—
Probability of occurrence within 100 normal localities	6	0	0	0
Same, within 100 localities near faults	100	66±	50±	15±
Same, within 100 lacustrine and paludal localities	100	40±	?	15±
Same, within 100 localities at igneous contacts	33±	100±	50±	66±

Normal means an ordinary fluvial deposit away from large faults and igneous bodies.
Upper part of table shows that among total number of calcite localities 31 per cent are found in the lacustrine deposits, only 14 per cent in normal deposits, 48 per cent near large faults, etc.
Lower part of table shows that every (i.e., 100 per cent) lacustrine deposit carries calcite, but only 6 per cent of the normal fluvial deposits carry it, etc.

This lack of normal, i.e., purely sedimentary, non-igneous, intrastratal activity within the Triassic is interesting, considering that both the general porosity and the permeability appear to be adequate and that at some places the Newark sandstones are known to carry water.

Accessory Minerals

Amounts present. In additon to the major constituents mentioned before, the Triassic rocks carry an abundant and varied suite of accessory heavy minerals. The quantity of the heavy residue varies greatly, ranging from 0.361 per cent up to 1.67 per cent of the total

sample. In certain specimens it may be even higher. Certain grade sizes may contain as much as 7.7 per cent of heavy minerals. The average heavy accessory mineral content of the Newark, not counting the micas, is estimated to be around 1.2 per cent. Detailed quantita-

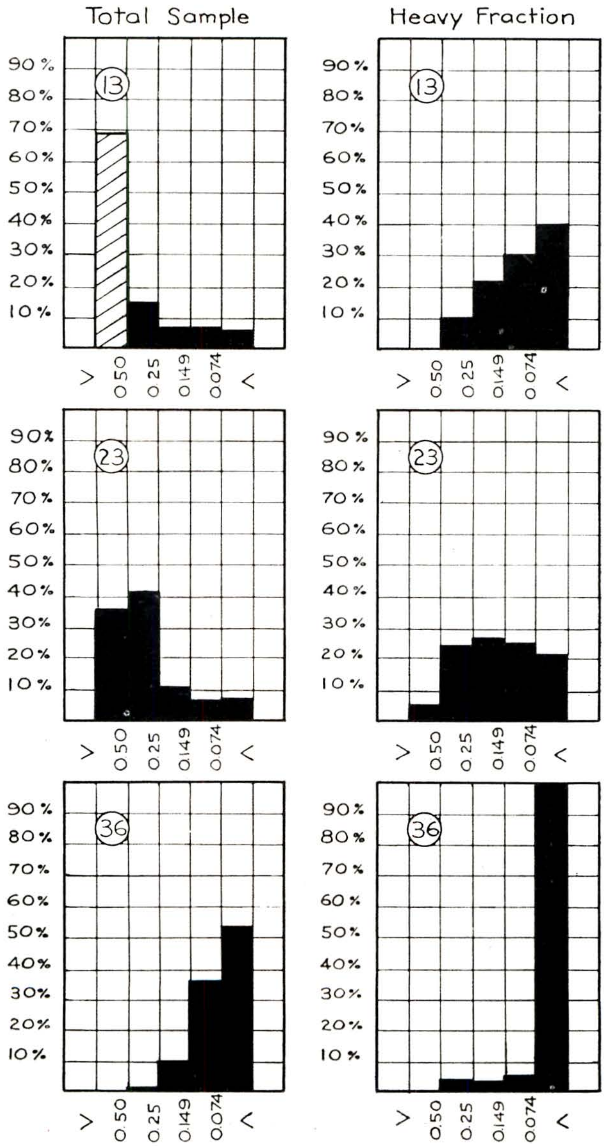


Figure 26. Comparative mechanical analyses of the light and heavy fractions of three typical Triassic sandstones. In No. 13 compare only solid portions of histogram since heavy residue was not obtained from the grade size above 0.5 mm. in diameter. (See Table 18.)

tive work was done on three typical samples, representing the pale and red arkoses, and the Redstone respectively. The results are summarized in Table 18 and shown graphically in Figures 26, 27, 28, 29, and 30.

As a whole, the heavy mineral suite from the Connecticut Triassic is very rich, both quantitatively (1.2 per cent is a high figure) and qualitatively, with no fewer than twenty-three major mineral species present (not counting the micas). The Triassic heavy suite

TABLE 18

DISTRIBUTION OF HEAVY MINERAL RESIDUES ACCORDING TO GRADE SIZE IN THREE TYPICAL TRIASSIC ROCKS

Occurrence	Grade size (mm.)	Per cent of heavies within each grade size	Distribution of heavy residue Per fraction	Distribution of heavy residue Cumulative
Loc. 13 (Fair Haven) Red Arkose	0.5 -0.25	0.129	9.85	9.85
	0.25 -0.149	0.390	20.55	30.40
	0.149-0.074	0.870	29.60	60.00
	†0.074	1.190	40.00	100.00
	Total †0.5	0.550	..	..
	Grand Total	0.167	..	..
Loc. 23 (Portland) Arkose	0.5 -0.25	0.91	27.10	27.10
	0.25 -0.149	4.10	26.10	53.20
	0.149-0.074	7.70	25.70	78.90
	0.074	5.20	21.00	99.90
	Total †0.5	2.46	..	..
	Grand Total	1.67	..	..
Loc. 36 (Redstone Hill) Redstone	0.5 -0.25	1.360	2.50	2.50
	0.25 -0.149	0.100	2.40	4.90
	0.149-0.074	0.236	4.20	9.10
	†0.074	0.630	90.87	99.90
	Total †0.5	0.363	..	..
	Grand Total	0.361	..	..

Note: "Total †0.5" refers to the amount of heavy minerals in the grade sizes finer than 0.5 mm. No bromoform separations were carried in the coarser sizes (excepting Sp. 23) since these coarser fractions hardly carry any heavy minerals.

"Grand Total" refers to the amount of heavy residue present in the entire specimen, i.e., includes the coarser grade sizes from which no heavy minerals were separated.

has a distinct "modern" character and appearance and looks very much like the residue from a recent Pleistocene glacial deposit.

Mineral suites. As is usual in heavy residues, the minerals of the Triassic can be pragmatically and conveniently divided into micas, opaque minerals or "iron ores" and non-opaque minerals. This division is based not only on appearance, but on the fact that these three groups have entirely different responses to current velocities: the buoyancy and "floatability" of the micas is the highest, that of the opaque minerals is the least, and that of the non-opaques is in-etrmediate. Hence frequencies should be recompiled on a 100 per cent basis for each group separately.

Although the micas form a reasonably high percentage of the Triassic rocks (2 per cent or more), they do not come down easily in the bromoform and hence constitute only an average of 20 per cent

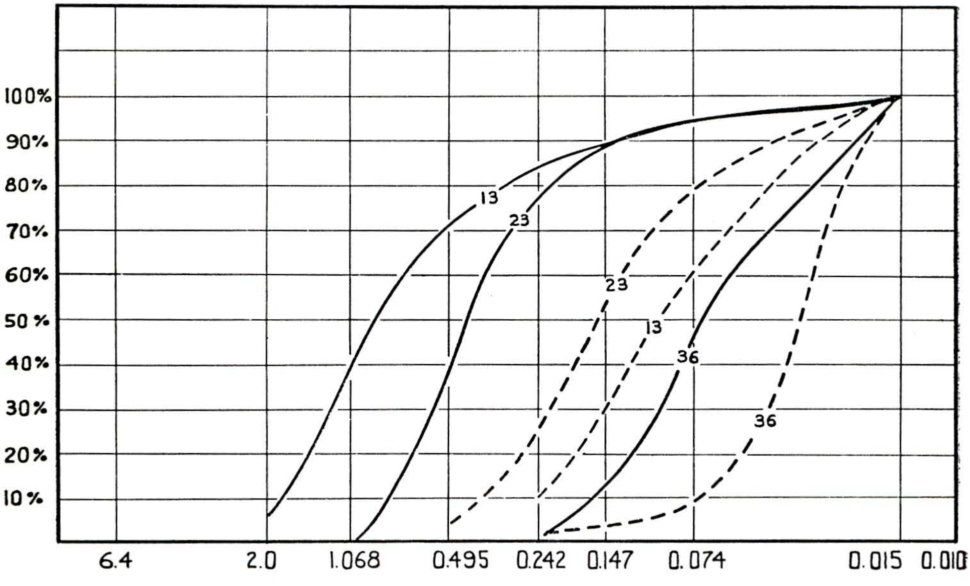


Figure 27. Cumulative curves of the grade-size distribution of the light and heavy fractions from three typical Triassic sandstones. (See Table 18.)

or less of the heavy residues. The opaque minerals or "iron-ores," mostly magnetite, with much ilmenite and locally, pyrite, make up approximately 32 per cent of the heavy residues, and the diagnostic, non-opaque heavy minerals the remaining 45 per cent and may go up to 50 per cent within the arkoses.

These ratios, as averaged from Table 4C, are given for the different rock types in Table 19 and shown graphically in Figure 31.

Detrital non-opaque minerals. As shown in Table 4C, the Triassic rocks, besides micas and iron ores, carry the following non-

opaque heavy detrital mineral species: apatite, augite, epidote, some of the fluorites, garnet, hornblende, indicolite, kyanite, monazite, rutile, sillimanite, staurolite, titanite, tourmaline, xenotime (?), zircon, and zoisite. The morphology and optical properties of these species have been described under Mineralogy in Chapter II.

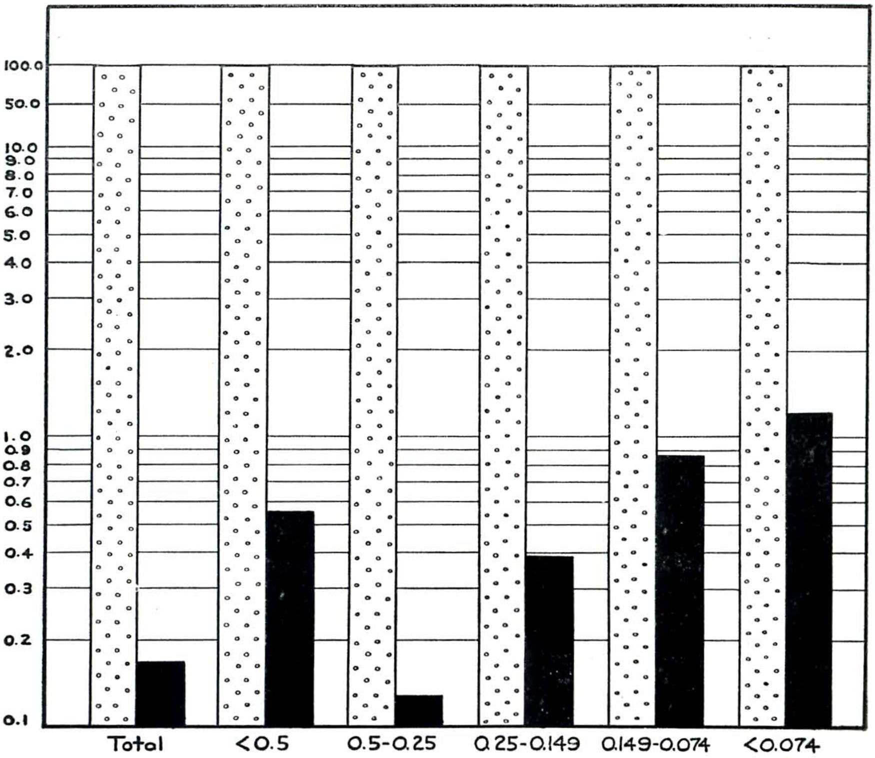


Figure 28. Comparative distribution of the light fraction (dotted) and heavy fraction (solid black) within specimen 13 (New Haven arkose from Fair Haven quarry).

It is possible to divide the garnet into several varieties based on color, the tourmaline into a series of types, also depending upon color, shape, and character of inclusions, and finally the zircon can also be subdivided into many types, in a way similar to tourmaline. Of these

TABLE 19

RATIOS OF BASIC HEAVY MINERAL SUITES

Rock Types	Micas	Opaque iron ores	Non-opaque rare minerals
Pale arkoses	28	27	45
Red arkoses	16	31	53
All arkoses	22	29	49
Redstone	12	30	58
Siltstone and shale	30±	40±	30±
Average of 45 samples	23	32	45

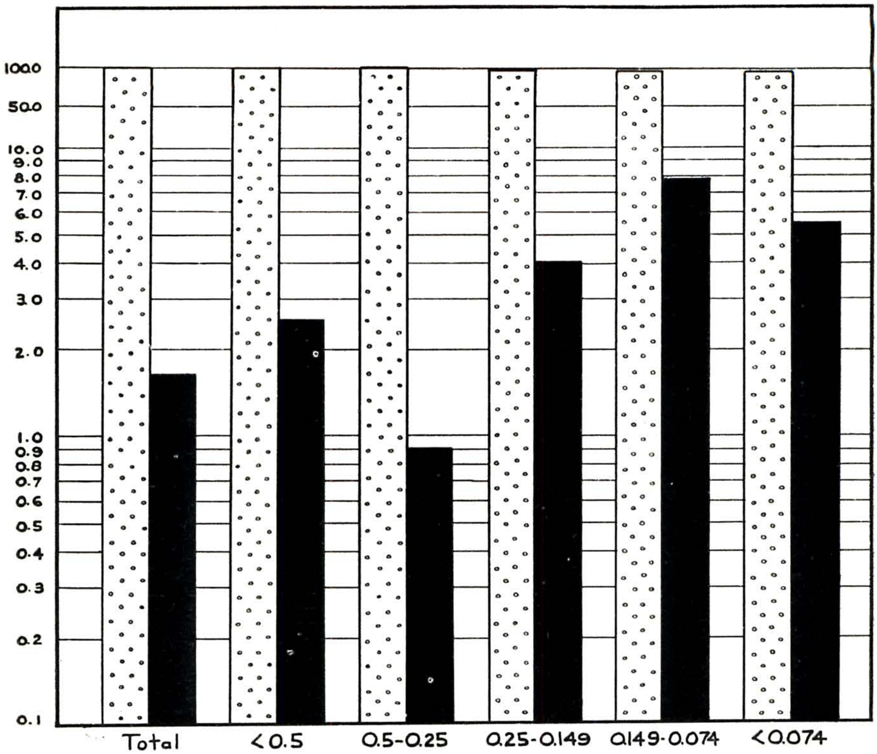


Figure 29. Comparative distribution of the light fraction (dotted) and heavy fraction (solid black) within specimen 23 (Portland arkose from Portland quarry).

possible subvarieties, the division of garnet into two classes (pink and colorless) and of tourmaline into three main classes (brown, pink, and green) has proved sufficiently diagnostic to be used in Table 4C.

As a whole the detrital heavy minerals of the Triassic are fresh, little weathered and, as said before, resemble to such an extent, in freshness, general appearance, and "feel," the recent heavy minerals from glacial Pleistocene beds that they may easily be confused with them.

Some of the grains, notably garnet and to a very minor extent staurolite, are at places etched and pitted, or may show so-called skeletal forms. Since transport in the Newark was rapid and brief, and as a whole all minerals show but little modification and rounding by transport, it is difficult to "date" the alteration and to say to what extent such pitting is pre-depositional (formed during the weathering of the regolith), or post-depositional (in the Triassic soil), or post-diagenetic and intrastratal. Some of the most marked etching

on garnet occurs in the basal New Haven beds, near the lower contact. This allows for two possibilities, since these etched grains are the first deposits from the older Triassic peneplane (and hence were subject to maximum pre-depositional weathering), and at the same time they are located near the lowermost contact plane of the Triassic at a place where considerable circulation of solutions took place. In this connection it should be remembered that augite, a notoriously unstable mineral, is totally unaffected by any kind of etching or alteration in these basal New Haven beds.

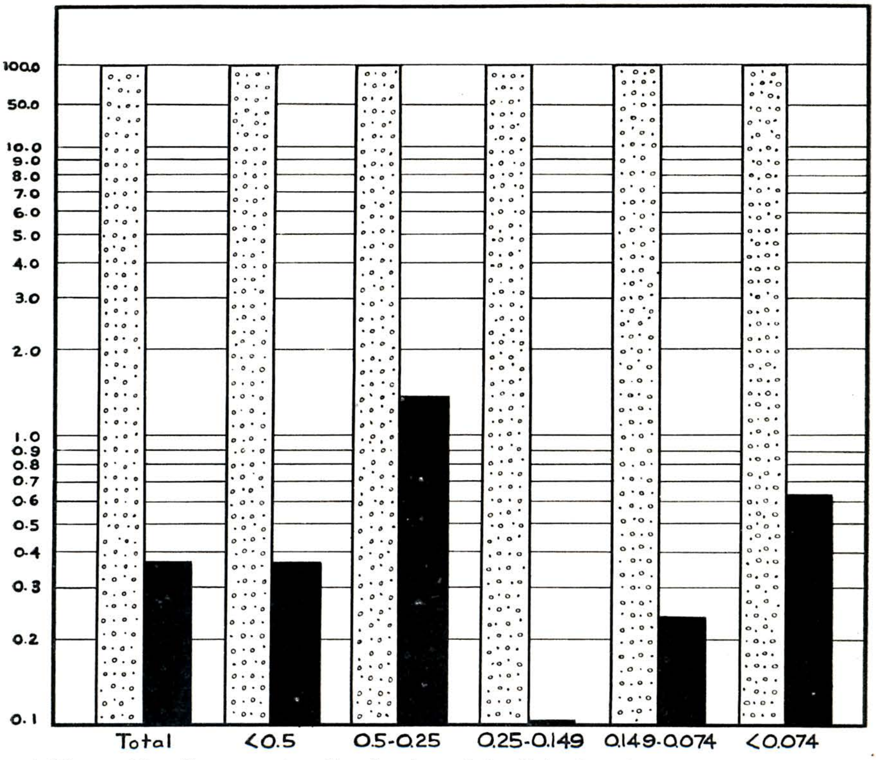


Figure 30. Comparative distribution of the light fraction (dotted) and heavy fraction (solid black) within specimen 38 (Redstone facies of New Haven arkose from Redstone Hill).

In many other portions of the Newark sections (in most of them as a matter of fact) garnet may show no pitting or etching whatsoever.

So far as "skeletal" appearance of the garnet is concerned (as contrasted with well-defined pitting), an examination of thin sections in specimens where garnet is very abundant (as at loc. 23 and many others) shows that many garnet grains within rocks have a tendency to fracture and pull apart, possibly as a result of structural

deformation (not of thin-section grinding since these garnet fragments are solidly embedded in the matrix). As loose grains within a heavy residue, some of these fragments may have a "skeletal" appearance.

No statistical work was done in trying to tie the possible etching of the garnets with the occurrence of major faults as was done for authigenic silicates and calcite. Nevertheless as a whole the alteration of the heavy minerals of the Newark, regardless of its origin, *is very slight indeed.*

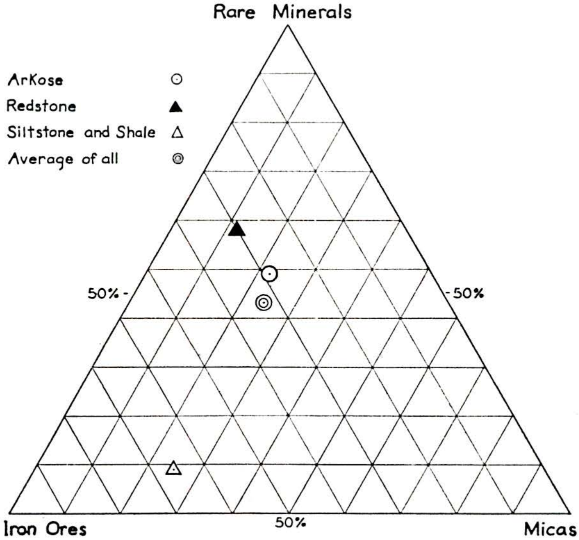


Figure 31. Averaged ratios between: (1) micas; (2) opaque iron ores; and (3) non-opaque rare minerals (from apatite to zoisite) within the medium and fine sand fractions of the Triassic heavy-mineral residues. See Table 4C for detailed data.

The division of the Connecticut Triassic into seven mineral zones and two geographic centers of alluvial fan building, according to the frequencies of the different non-opaque detrital minerals, has been presented in Figure 6 and Tables 5 and 6, and has been discussed in Chapter III under "Stratigraphy."

Long-range correlation between the same Triassic horizons through the use of heavy minerals is demonstrated in Tables 9 and 10 and shown graphically on Figures 13 and 14.

The mixing in all proportions of the two petrographic detrital end members of the Newark (granitic vs. clayey detritus) has no effect upon the mineral frequencies and hence extremely dissimilar lithologic types can easily be compared and correlated.

Authigenic non-opaque heavy minerals. The chemically formed heavy minerals of the Newark include anatase, barite, and some of the fluorite and rutile.

Large-scale occurrence of most of these authigenic minerals either takes place within the lacustrine beds, or is related (with very few exceptions) to the presence of igneous contacts, and major faults, or similar zones of large-scale fluid circulation. On a small scale, however, anatase is present practically within every heavy residue.

Chemical composition. An analysis of the Portland arkosic "Brownstone", as quoted by Pirsson and Knopf, is as follows:

SiO_2	69.9
Al_2O_3	13.6
Fe_2O_3	2.5
FeO	0.7
MgO	Trace
CaO	3.1
K_2O	3.3
Na_2O	5.4
H_2O	1.0
Total	99.5

Coarse Clastics

Fanglomerates

General features. Under the term fanglomerates will be described the extremely angular, poorly sorted and poorly sized, coarse clastics found along the Great Fault. These rudely bedded sediments form the upper apex of the numerous Triassic alluvial fans that radiate westward from the fault. Inasmuch as these fanglomerates gradually pass into conglomerates, it is necessary to draw some empirical dividing line between these two rock types. The term fanglomerate will be restricted to a rock in which at least 50 per cent of the pebbles are decidedly angular and possess sharp edges. Lack of sorting and lack of sizing usually go hand in hand with extreme and widespread angularity of the constituents. Real fanglomerates (as defined above) do not extend more than 2,000 feet west of the fault. Percival described the fanglomerates in a way which was not surpassed until the days of Longwell, 80 years later. Percival writes (1842, p. 447):

> "Along the immediate Eastern border of the Secondary, a band, usually of not great width, extends throughout the greater part of the present range, composed of a very coarse conglomerate, consisting chiefly of slightly altered angular fragments of Primary rocks, usually distinctly traceable to the adjoining Primary formations. These fragments are usually but slightly cemented by a dark red argillaceous cement, and in some instances, readily disintegreate, forming a debris resembling that of Primary ledges. In one instance, E. S. E. of Middletown city, a bed of dark bituminous micaceous shale occurs in connexion with this band of conglomerate".

Color, structure, and texture. The Great Fault fanglomerates when fresh are usually bluish purple or reddish purple with a brilliant shiny surface. This purple color is produced through a mixture of red and green pigments furnished respectively by hematite and chlorite, both of which are common in the fanglomerates. This purplish color and shiny lustre are uniformly present from New Haven to Mt. Toby. The reddish tinge is due to the presence of red clay in the matrix. At some places this clayey admixture becomes sufficiently abundant to give to the fresh specimen a maroon color. Upon weathering, the fanglomerates become dull grayish purple or red.

The sizing is extremely poor (Plate XXV-A and B). At some places the rock consists of an extraordinary jumble of unsized material ranging from rock flour or red clay up to boulders 6 feet in diameter. Such large boulders, however, are unusual. The average size of the constituents ranges between 8 and 12 cm. only.

Most of the constituents are extremely angular with sharp, unblunted edges. At some places they are almost unrecognizable from a fault or talus breccia. At some places (such as loc. 22), however, subangular and even rounded material made up of the softer schist pebbles is present. This may indicate the presence of streams of somewhat greater length than the usual very short canyons of the fault scarp, although the rounding of the soft schist pebbles can proceed with extreme rapidity and in a very short distance, possibly a matter of hundreds of feet only.

The pebbles are bonded by ferric oxide, red clayey cement, or non-weathered rock-flour, or are directly stuck to each other, at places showing a slight amount of mutual inter-penetration.

The bedding is very poor and usually in the fanglomerates proper it can be recognized only with difficulty. The fanglomerates, however, at many places are interbedded with perfectly banded arkoses (Plate XXV-A), dark siltstones (Plate XXIV-A), red laminated shales, and lignite-bearing organic beds (Chestnut Mountain). Large, oriented, tabular boulders in a clayey matrix possibly suggesting a mudflow, have been found at only one place, near Lake Quonnipaug, 1,500 feet west of the fault. Otherwise, the fanglomerates do not show evidence of mudflow transport. The angular material seems rather to be of talus origin, possibly directly slumped into place or, more probably, somewhat reworked and transported for a very short distance by torrents into the beds of which it slumped through the undermining of steep cliff-like canyon walls.

Composition. The fanglomerates contain every crystalline rock type outcropping east of the Great Fault for a distance of 3 miles at least, and some types which can not be matched at the present time among the crystalline rocks east of the fault. Fragments of the immediately adjoining Bolton schist are more commonly present than

of any other rock type. Near Branford the fanglomerates contain pieces of vesicular basalt, a fact which indicates a temporary retreat of the scarp and a slight extension of the lava beyond the Great Fault. Differential prediagenetic weathering can be observed both in hand specimens and in thin sections.

The East Portland outcrop (loc. 22, Plate XXV-A) was studied in some detail. Here fanglomerates outcrop for a length of 500 feet in a new highway cut. The pebbles occurring in two surface areas 250 feet apart and each approximately 10 x 10 feet in size were counted, their composition and angularity determined, and the results averaged.

In the northern part of this exposure there is a rude bedding with arkosic and conglomeratic layers 1 to 1 1/2 feet thick alternating with fanglomerates. In the latter (fanglomerates) only the flatter pebbles are roughly oriented, otherwise the constituents form a structureless jumble of rock fragments, 90 to 95 per cent of which consist of pebbles and cobbles, and from 5 to 10 per cent of matrix.

Near the southern end, layers of pebbly arkose 1 foot thick alternate with layers of fanglomerate 4 feet thick. The arkosic layers contain from 30 to 90 per cent of sand, the balance being pebbles and a few isolated larger cobbles (up to 10 cm. in diam.).

In the fanglomeratic areas the largest boulder (of quartzitic Bolton schist) reached 35 x 18 x 18 cm. in size. The next largest piece (30 x 25 x 15 cm.) was an angular fragment of vein quartz. From 60 to 70 per cent of the rock fragments do not exceed the size of a pebble (6.4 cm. diam. and 33 cm^2. in maximum area).

In respect to angularity, 46 per cent of the fragments are angular and sharp-edged, 36 per cent are subangular (i.e., half of the edges are somewhat blunted), and 18 per cent are rounded. Three-quarters of the rounded fragments are of soft schist, mostly (two-thirds) in the larger cobble size (6.4 cm.).

In respect to composition, 60 to 65 per cent of the fragments consist of Bolton schist (40 to 45 per cent of the softer, green phyllitic facies, and 20 to 22 per cent of the harder, grayish schistose-quartzitic facies), 10 per cent of Glastonbury granite-gneiss and related pegmatitic and pink feldspar fragments, 2 per cent of vein-quartz pebbles, and the balance (22 per cent) of a garnetiferous mica schist.

Conglomerates

Conglomerates form approximately 10 per cent of the Triassic section. Although a strict comparison of the strata from east to west is difficult, for we are dealing at all times with different hori-

zons, it seems that in general conglomerates decrease away from the Great Fault. Conglomerates form 13 per cent of the Portland formation as a whole, and in the portions nearer to the eastern boundary, this amount rises to 20 and 22 per cent. In the lower New Haven arkose, 10 miles west, this percentage drops to 3 and 5 per cent.

Usually conglomerates occur in patches, lenses, pockets, and thin beds. At certain horizons, however, especially at the very top of the New Haven arkose, relatively thick beds of conglomerates are present (Russo Street, Foxon Park, etc.). These are probably related to periods of intense tectonic activity and uplift of the fault scarp preceding the first great period of volcanism. Pebbles up to 6 inches in diameter are common at all levels everywhere in the valley, and boulders as large as 1 1/2 feet have been observed at one locality east of Wallingford.[7] Recognizable pebbles of the Stony Creek granite with its graphic intergrowths, a feature of the upper New Haven arkose, are very abundant at East Rock and Ridge Road, and go as far west as the Pomperaug area, again indicating the local character of much of the Triassic material.

Medium-Grained Clastics

Arkoses

General features. Medium-grained clastics form almost 65 per cent of the section (76 per cent of the New Haven arkose, 58 per cent of the Meriden formation, 57 per cent of the Portland formation). They have been generally referred to in the literature and among geologists as arkoses. This is a somewhat generalized usage, for, as shown by Knopf, true arkoses in the restricted sense are only such feldspathic sedimentary rocks as have the composition and appearance of a granite. Such true arkoses are abundant in the upper New Haven beds of southern Connecticut (derived from the Stony Creek and Lighthouse Point granites). On the other hand this term can be applied only in an extended sense to the white, grayish, and dark (some are black) feldspathic sandstones of the Meriden formation, or to the fine-grained, brick-red feldspathic sandstones of the central Connecticut Redstone facies of the New Haven arkose, or, finally, to the phyllite-bearing arkoses (semi-graywackes) of Shepard Avenue and South Meriden. These last rocks are so full of phyllite and schist fragments as to border in some instances on a graywacke and in appearance they almost suggest a breccia.

In the lower New Haven beds the amount of feldspar rarely exceeds 35 per cent, and sometimes sinks as low as 5 per cent. It is only where erosion uncovered the Stony Creek granite mass in the beginning of upper New Haven time that true granitic-appearing arkoses become a feature of the section in the southern part of the valley.

[7] The average size of the pebbles, however, ranges between 3 and 6 cm.

However, and regardless of what has been said before, the term arkose seems to have taken among geologists a somewhat broader, almost generic meaning, perhaps like the term granite in the extended sense among igneous rocks. Nevertheless there are so many different types of feldspar-bearing sandstones in the Connecticut Triassic, that in the present discussion, the term arkose is applied only to feldspathic rocks whose feldspar is sufficiently conspicuous to be seen easily, i.e., megascopically, in hand specimens.

The most remarkable features of all these arkoses are their angularity and high content of unweathered feldspar, to which can be added, for the truer arkoses and the semi-graywackes, an extremely poor sizing.

Color, structure and texture. The Connecticut arkoses, when fresh, are gray, purplish-gray, pink, or red. The pink or red color is due either to the presence of naturally pink feldspar, or of feldspars reddened by incipient chemical decay, or of hematite. This red iron-oxide pigment may either occur as a thin film coating the sand

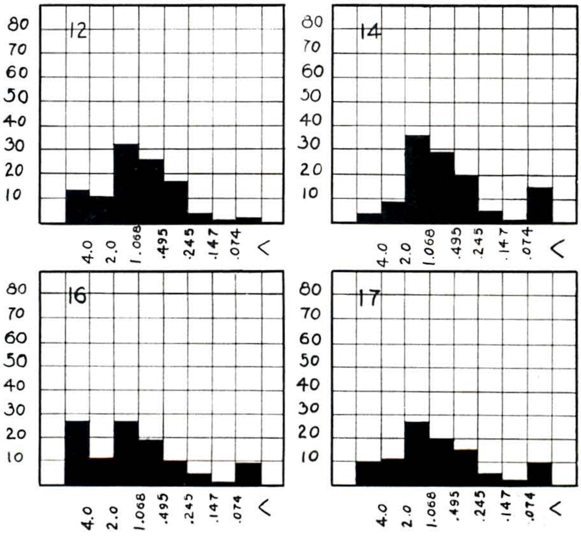


Figure 32. Histogram showing mechanical composition of four typical Triassic arkoses (locs. 12, 14, 16, and 17). Clayey matrix is included.

grains, or it may be disseminated throughout the matrix and cement of the rock. Not less than 45 per cent of the arkoses are red, and in at least half the instances the color is due to red iron pigment. Nevertheless the influence of feldspar upon red color can be seen from the fact that in the pale arkoses the ratio of quartz to feldspar is 63 to 37, whereas in the red arkoses it is 53 to 47.

Upon weathering, the paler arkoses become grayish-purple or more often reddish. The pink and red varieties turn bright red. This increase in red color upon weathering has led to the general impression that all Connecticut arkoses are red, whereas, in fact, they are variegated, and only half of them are pink or red when fresh. Mottling in gray and green on weathered surfaces can be seen at many places. As a rule the arkoses show only the rudest sort of bedding and banding due mostly to layers of finer silty or shaly material. Cross-bedding, cut-and-fill stratification, channelling, and intraformational unconformities are extremely common.

The arkoses in general are coarse and poorly sized. Great variations in sizing and coarseness can take place within a stratigraphic range of only a few feet. Figure 11 shows the variations in grade sizes of three arkose layers within a total range of 9 feet (loc. 21, Dawson Lake). Figure 32 shows the histograms of four typical arkoses from different levels of the New Haven beds. As a whole the cumulative percentage of material coarser than 0.5 mm. (i. e., coarse sand and coarser) varies in the arkoses between 30 and 86 per cent and averages close to 65 per cent. The cumulative percentage of gravel and pebbles varies from 2 to 38 per cent and averages around 15 per cent. The median diameter is between 0.546 and 0.725 mm.

Most of the grains are angular, many of them extremely so. The angularity varies according to the mineral and the grain size. Feldspars as a rule are better rounded than quartz. This is due to their lower coefficient of resistance to abrasion (150 as against 245 for quartz, according to Freise's scale, 1931). The propensity towards cleavage is apparently insufficient to split the grains and prevent rounding.

The great mass of the grains in a typical specimen can be described as subangular, or even angular, i.e., the edges of the grains are sharp or only very slightly blunted. Rounded or even subrounded material (i.e., grains in which at least half the edges are distinctly rounded and blunted) is decidedly rare.

The grains are bonded by ferric oxide, red clayey matrix, colorless clayey matter, or calcite-cement. The ferruginous varieties of cement greatly predominate. Calcite is mostly secondary. Some of the pure white kaolinitic matter may be the result of weathering. The amount of cementing matter varies between 3 and 16 per cent.

Under the microscope the irregular character of the texture and the lack of orientation and parallelism of the sand grains can be clearly seen. Even mica flakes may fail to show any orientation or only a very rude one. The larger grains are embedded in a matrix made up of the smaller grains (Plates VIII-A and B). At many places grains show crushing and mutual accommodating.

Composition. Among the truer granitic-appearing arkoses, such as the Fair Haven arkose, the percentage of feldspar may approach 50 per cent. Otherwise, it may be lower. Many arkoses contain 20 per cent or less of feldspar. Their appearance, however, due to the conspicuous pink color of the feldspar, is arkosic, and they have been generally referred to as arkoses rather than feldspathic sandstones. Table 20 shows the composition of several rocks of arkosic appearance from the New Haven beds.

TABLE 20

COMPOSITION OF SOME MEMBERS OF THE NEW HAVEN ARKOSE

1. Roaring Brook, at contact with Hartland schist (loc. 39)	
Quartz	50%
Feldspar	18-20%
Microcline 85%	
Albite 15%	
Calcite	27%
Muscovite	1%
Ferruginous cement	3%
2. Roaring Brook, 60 feet above contact (loc. 38)	
Quartz	80-85%
Feldspar	5%
Microcline 95%	
Albite 5%	
Muscovite	5%
Matrix and cement (iron oxide, sericite, kaolin)	8%
3. Dawson Lake, 30 feet above Orange phyllite (loc. 21)	
Quartz	80%
Feldspar	8%
K-feldspar 80%	
Sodic-oligoclase 20%	
Muscovite	1%
Matrix and cement (iron oxide, sericite, kaolin)	12%
4. Federal Hill, Bristol, at fault, 1,000 feet (approximately) above Hartland schist contact (loc. 37)	
Quartz	70-75%
Feldspar	15-20%
Microcline 95%	
Albite 5%	
Matrix and cement	9%
5. Northford, directly under lower lava flow (loc. 12)	
Quartz	60%
Feldspar	36%
Microcline 65%	
Albite 35%	
Matrix and cement (iron oxide, sericite, kaolin)	4½%
6. Fair Haven, Blakeslee quarry (loc. 13)	
Quartz	55%
Feldspar	40%
Microcline 95%	
Sodic-oligoclase 5%	
Micas	2%
Matrix and cement (iron oxide and calcite	6%

Certain of the Triassic arkoses are intermediate in composition between real arkoses and graywackes. Some of the arkosic "brownstone" of Portland, although still a real arkose, generally contains a considerable amount of rock fragments: quartzitic, mica-schist, and chlorite schist. However, other brownstones, also from Portland, may carry as much as 65 per cent of feldspar.

The feldspar of the arkoses is mostly microcline, with smaller amounts of plagioclase. The latter is invariably albite or sodic-oligoclase, practically never more basic than An 15. The predominance of microcline over plagioclase is due less to any superior resistance to decay or abrasion of microcline over sodic-plagioclase, than to the original abundance of microcline in the crystalline source rocks. Although the feldspar of the arkoses is mostly fresh, it is not universally so. Differentially decayed feldspar is a feature of many arkoses: in the same hand specimen different grains of microcline may show various degrees of decay or the same may be true of plagioclase grains (Plate XXIX). This has been seen in all specimens showing this differential weathering that were obtained from a quarry or a very fresh outcrop, and hence not subjected to recent weathering. Thus it is probable that this differential decay of feldspar grains can be explained best as being of primary origin, i.e., as having taken place before the consolidation or even before the deposition of the arkoses. Depositionally most arkoses are channel deposits.

Replacement of feldspars by secondary calcite may be common in the Triassic arkoses. Although microcline is generally considered to be much more resistant to subaerial chemical alteration than plagioclase, it is found to be much more frequently replaced by intrastratal (hydrothermal ?) calcite than is plagioclase (Plate VI-A).

The quartz of the arkoses usually shows strain shadows, in places extremely pronounced in the metamorphic varieties (Plate VI-B). In addition to quartz, feldspar, and rock fragments, the Connecticut arkoses contain all the minerals described in the section on Mineralogy, with the exception of dolomite, siderite, and pyrite.

Feldspathic Sandstones and Redstone

General features. Under the term feldspathic sandstones will be described such sandstones as do not have an arkosic appearance in hand specimens, i.e., rocks in which feldspar is not conspicuous megascopically and can be identified only with difficulty or not at all.

Feldspathic sandstones are white, gray, red, or black. Most of them are red in the New Haven and Portland formations and white or gray in the Meriden beds. The sandstones are finer-grained and in some cases better sized than the true arkose. The percentage of coarse and very coarse sand may rise as high as 35 per cent, but

averages only 15 per cent. Insignificant amounts of gravel are present in less than one-tenth of the specimens.

The constituent grains are angular or subangular and show only faint rounding in some of the Meriden beds. The feldspathic sandstones vary greatly in texture and appearance and can best be described by types.

Redstone type. The most important of all the feldspathic sandstones is a brick-red clayey sandstone which forms over 4,000 feet of the New Haven section west of Meriden, and is also prominently represented at other localities. This rock has been named after Redstone Hill, west of Southington, where it is well exposed. The Redstone consists of angular quartz and feldspar grains embedded in a matrix of red hematitic clay (Plate VII-B). This clayey matrix may constitute as much as 45 per cent of the rock. It averages between 25 and 30 per cent and only rarely falls below 25 per cent. The sand grains consist of quartz, feldspar, and abundant micas (muscovite and biotite). The percentage of feldspar is high (around 30 per cent as an average). A notable feature is the freshness of many of the feldspars and of the biotite. The association of unweathered grains of these susceptible minerals with the bauxitic, gibbsite-bearing red clay of the matrix, the product of deep chemical decay, suggests that the rock is a purely mechanical mixture of material coming from two different sources or, as shown previously, from two different loci of mechanical and chemical weathering within the same source area.

At most places the Redstone is almost massive, and shows only the poorest of structures. At others, it is banded (2-4 cm., at places 1-2 cm.) and layered (10-20 cm.). Cross-bedding is usually absent or at least very hard to see. At Cheshire Street, in a highway cut on the south shore of the Quinnipiac River (loc. 35, upper New Haven arkose) the Redstone contains poorly preserved plant remains, apparently Equisetes. They are red cylindrical bodies formed through the filling of hollow stems of rushes with the soft red mud of the matrix, and traces of the original plant structure are preserved on the outside of these stems.

Because of its high clay content, the Redstone is a very weak rock, and resists erosion poorly. The Redstone areas show very subdued topography. Perfectly rounded pebbles and boulders of Redstone are a feature of the Pleistocene glacial deposits of the upper and middle Quinnipiac Valley.

Other red sandstones do not possess the high amount of clayey matrix characteristic of the Redstone. They really are fine- and medium-grained arkoses which, however, are so heavily coated with red iron oxide that their arkosic character is not apparent megascopically. These sandstones contain much mica, and as a rule are

well layered and banded. Their micaceous platy character, good stratification, and relatively fine grade size set them conspicuously apart from the typical coarse arkoses of the Triassic. As a result, these sandstones have been referred to rather loosely as shales, which they are not. The term "shale" has also been frequently misused, both in Connecticut and in other Triassic areas, to cover not only these red micaceous sandstones, but also most of the flaggy and relatively fine-grained clastics such as the white and gray micaceous sandstones and practically all the siltstones. These red sandstones are frequently ripple-marked and also show mud cracks and dinosaur tracks. The mud cracks may have a diameter up to 25 cm., but in general are very shallow (0.5-1 cm.). Some of these desiccation features are impressed directly upon the sandstones, but most of them have been recorded because an extremely fine and inconspicuous, barely visible layer (1 mm. or even less) of clayey shale between two sandstone layers received and preserved the impression proper, whereas the underlying sand acted only as backing and support for the clay. The Redstone and other red sandstones are mostly flood plain deposits.

White and gray feldspathic sandstones. Pale-colored sandstones are extremely common in the upper Meriden formation. They are typically white or whitish-gray, dense, sugary appearing rocks, weathering to a dirty white or yellowish-white in rusty patches and spots, with a characteristic speckled and spotted appearance. They are usually well sized, containing up to 50 per cent of the grains in the medium sand fraction. The grains are characteristically closely packed together (Plate IX-A) with almost no cement (secondary silica, kaolin, and rarely a little calcite). The feldspar content may be very high (up to 70 per cent and as a rule not less than 50 per cent). They usually appear to be massive with only a poor parting, 10-20 cm. apart, on account of the concentration along some bedding planes of mica flakes or small flattened clay galls; but, upon careful examination, they frequently show a cut-and-fill stratification on a small scale (5 to 10 cm.), marked by differential weathering of limonitic bands. Some of the light gray feldspathic sandstones are red sandstones bleached by thermal contact action near the vicinity of igneous bodies (see description of contact rocks at Reed Gap).

Dark-colored feldspathic sandstones. The dark color of these rocks is due either to the extreme abundance of biotite or chlorite or to the presence of organic, mostly carbonaceous, matter. Biotite and chlorite occur in extremely large amounts in some sandstones near the Great Fault, and in these places they account for the color, but otherwise the dark tints are due to organic material. The color varies from light gray, through grayish purple, to almost black.

These dark organic rocks are generally medium- or fine-grained and finely banded (1 to 5 cm.) and layered. They are interstratified with very thin layers of black shales and layers of almost pure mica. The planes of stratification, as a rule, are not flat parallel, but con-

torted. Carbonaceous matter is abundant and fragments of fossil wood occur at many places. Ripple marks, mud cracks, and animal tracks are also common.

These dark sandstones usually have a high ratio of matrix and cementing matter (25 per cent is not uncommon) in which are embedded sand grains of various sizes. This bond consists of calcite, dark clay, and finely micaceous material. Under the microscope many of these sandstones have the appearance of small-scale conglomerates or rather breccias. Also, minute desiccation cracks in some of the specimens can be seen to be filled with reddish dust, thus suggesting a subaerial exposure. Many of these dark sandstones appear, thus, to have been formed in a paludal environment, with plenty of vegetation and intermittent swampy water bodies. Others, however, are fairly massive for a thickness of 1 or 2 feet, and contain an abundance of carbonized wood, thus suggesting more permanent swamps.

Fine-Grained Clastics

Siltstones

Siltstones form 13 per cent of the New Haven arkose, 11 per cent of the Meriden formation, and 23 per cent of the Portland formation. In the past the siltstones of the Triassic have been generally referred to as "shales". They are, however, much too coarse and gritty to the touch to be called by such a term. At one end the siltstones pass into fine-grained sandstones, on the other, they grade into shales.

The red siltstones, which are by far the more common, can almost be considered as being very fine-grained feldspathic sandstones of the Redstone type. They all show excellent banding and stratification. There are usually three or more orders of banding. The finest lamellae (0.25 mm. thick) unite in bands 2 mm. to 2 cm. thick which form major layers of variable thickness. Stratification planes are marked by accumulations of mica flakes. Fine cut-and-fill stratification, ripple marks and, at places, mud cracks are common. Some of the cut-and-fill stratification is on a microscopic scale, being distinctly marked in thin sections (Plate XII-A), by an alternation of curved dark and light bands, the darker layers being especially rich in iron oxide. Red siltstones are flood plain deposits.

The siltstones are made up of very minute angular grains (15 to 75 per cent) of quartz and feldspar embedded in a matrix or paste (25-85 per cent) made up mostly (two-thirds) of red ferruginous clay or directly of hematite and of a pale, almost optically inert (sub-isotropic) semi-micaceous material (one-third) which is difficult to resolve under the microscope. X-ray tests show this to be mostly kaolinite, with some gibbsite and illite. Some of the siltstones are really micro-conglomerates or rather micro-breccias.

The dark-colored siltstones (black, gray, blue, and green) are very similar to the red ones, except that the red iron oxide is replaced by organic matter and pyrite. A fine example of microscopic cut-and-fill stratification in a dolomitic siltstone is shown on Plate XII-B.

Shales

Shales form 2 per cent of the New Haven arkose, 40 per cent of the Meriden formation, and 7 per cent of the Portland formation. They are soft and unctuous to the touch. Banding and lamination are excellently developed; fissility becomes prominently visible after weathering and then some of the shales may split into paper-thin layers. Several orders of banding magnitude are present as in the siltstones. Current and desiccation features are also to be seen, although desiccation marks are absent in the lacustrine types.

The red shales can be considered as siltstones in which the ratio of grains to the ferruginous clay matrix is less than 15 or 20 per cent.

The dark shales (gray, black, green, and blue) are made up of organic matter mixed up with micaceous and kaolinic material. In a typical specimen the mass of the shale consists of 40 to 50 per cent of a dense, optically almost inert paste and 50 to 60 per cent of tiny, well oriented micaceous flakes which account for the lamination of the rock. Bedding planes may be marked by accumulations of mica, secondary barite, and pyrite. The organic matter either occurs as disseminated black spots or is concentrated in layers and bands.

The shales may contain calcite layers and calcareous concretions. Some of these are of secondary, intrastratal origin, as can be proved by the fact that they cut across fractured and bisected sand grains.

The shales not only occur as definite beds, but at many places in the coarse arkosic series they form small curved pockets and layers (1-50 cm. long, 1-5 cm. thick). These thin, but very tenacious layers are apt to receive impressions of animal tracks and other desiccation and current features and to preserve them, thus explaining the occurrence of such features amid coarse clastics.

The dark shales at many places carry plant and fish remains. These dark horizons also contain large amounts of pyrite, which, upon weathering, give the beds a yellow, rusty appearance.

To avoid repetition, regional and local features of the shales, their distribution, their fauna and flora, and their genetic significance are discussed in the chapters on Stratigraphy and Climate.

Calcareous Rocks

Limestone at Northford

General features. Thin (1/2-3 ft.) layers of impure calcareous rocks are found at many horizons of the Meriden formation. A real

limestone layer, up to 14 feet in thickness, is present at the very base of the formation, immediately or almost immediately above the lower lava.

At its type locality, (locs. 9 and 10) in Coe's quarry, north of Northford, the limestone is a banded and layered bluish-gray rock passing into a micaceous silty sandstone at both top and bottom. The limestone is 13 feet thick.

The limestone directly above the basal sandstone layer is dark blue, and of a coarser grain than the main limestone mass higher up. These lower layers contain a considerable amount of sand. They are finely banded (0.5 to 3 cm.), the bedding planes being marked by an accumulation of mica flakes.

The main limestone body is of a light to dark bluish-gray color, weathering to a light yellowish-buff. There is a principal banding (about 35 cm. apart), and also a finer banding or lamination (1 to 3 mm.). The latter is often curved. In addition to these bedding planes there are innumerable curved, lens-like layers of sand and mica flakes, usually bent and contorted. Many small cavities are present, either empty or filled with white or yellowish calcite crystals or reddish masses of iron oxide. The clastic impurities stand out prominently after etching the limestone with HCl (Plate XIII-B), and the rock's color changes to a light gray after acid treatment. The rock possesses a very irregular fracture.

The upper 3 or 4 feet contain more sand cavities, the clastic layers are more abundant, and finally the limestone passes rather abruptly into a silty sandstone very similar to the one which underlies it.

According to many analyses made by the Connecticut Agricultural Experiment Station, which has tested the limestone as a fertilizer (E. M. Bailey, analyst), the amount of CaO ranges from 50.37 to 55.81 per cent, and that of MgO from 0.72 to 0.80 per cent. Approximately 8 per cent of the rock is insoluble in acid.

Clastic impurities constitute 7 per cent of the rock (Table 21). The limestone reacts violently with cold HCl and a black foam immediately forms at the top of the beaker. This black foam (a fraction of 1 per cent of the insoluble residue) was found to consist of shapeless particles, too minute to be resolved under the microscope. They are of organic origin (combustible) but are not petroleum hydrocarbons, for they are insoluble in ether. The sandy part of the insoluble residue is a white arkosic sand.

Limestone layers, with algae (?). In a thin section from a layer 6 feet above the base, the rock is seen to be an impure limestone with numerous sand grains scattered throughout or segregated into irregular layers. The calcareous paste, which forms 90 per cent of

the rock, is by no means uniform; it varies from a fine crypto-crystalline aggregate of dark (almost black) calcite to a coarse-grained mosaic of large recrystallized colorless calcite grains. A definite banding and cyclical arrangement can be made out. A depositional cycle starts with a sandy layer, followed by fine-grained dark calcite, and, finally, by coarse limpid calcite. Often the sandy layer is absent, and the banding is confined to the calcite. Curving, banding, contorting and a lensoid texture complicate matters. Some of the planes are marked by a parallelism in mica flakes or by iron oxide and organic stringers.

Disseminated in the calcite mosaic can be seen round or oval calcareous bodies which appear to be of organic origin. The larger bodies (Plate XIV-B) may be interpreted as specimens of blue-green, fresh-water algae, the so-called "water biscuits" (Charophyta). Similar varieties have been described by Roddy, and are also illustrated in Milner. Other smaller round bodies (Plate XIV-A) strongly resemble the algal spores of the class Charophyta, as described, among others, by Peck. These spores are hollow spheres covered with spiral ridges which, in a thin section, look like a geared wheel. The resemblance of the round bodies of the Northford limestone to these spores is marked indeed. The hollow spheres are filled with coarse crystals of re-crystallized calcite. Finally, some branching and dendritic bodies, usually of a dark color, appear possibly to be the stems of fully grown Charophyta. Unfortunately no fossils were discovered in hand specimens, and for this reason the evidence for the presence of algae is limited so far only to thin sections. In addition to these organic bodies, concentric growths of calcite can be seen around some quartz grains. It is difficult to say whether these are young algae growing around a nucleus, or simply incipient oolites.

The clastic impurities consist of an arkosic sand (Table 21). The sorting and rounding are fair. Some of the quartz grains have irregular surfaces which may suggest, possibly, corrosion. The quartz is usually of the igneous variety (few inclusions, no strain shadows). The microcline is often replaced, and the plagioclase is also frequently altered. In one or two instances, secondary growth of quartz in optical continuity with the parent grain was noted. Titanite and barite (authigenic) are also present.

Eight feet above the base (specimen 10), in a thin section, the rock is seen to be made of a calcareous paste in which are imbedded larger calcareous bodies and many sand grains. The variations in color (black to colorless) and in size (fine to coarse) of the main calcite mass are very similar to those already described. An interesting feature of this section is the presence of extremely numerous layers and bands, usually extremely curved. Often the contact planes are serrated and marked by iron-oxide flakes.

Scattered throughout the calcite matrix are larger calcareous bodies which remind one somewhat of Charophyta spores, but they

are much more doubtful than those in the preceding specimen. Irregular clusters of coarse, light-colored calcite grains are also present. Variations in the calcite reflect the same depositional cycles mentioned before.

The composition of the insoluble residue is given in Table 21. The quartz, microcline, and oligoclase show the same characteristics as in the preceding specimen. Some of the quartz grains are well rounded; generally they are subangular or subrounded. Some of

TABLE 21

MINERAL COMPOSITION OF THE INSOLUBLE SANDY FRACTIONS OF THE NORTHFORD LIMESTONE

Micaceous sandstone under limestone	
Quartz	47%
Feldspar	53%
K-feldspar (mostly microcline), 60%	
Sodic oligoclase, 15%	
Indeterminable, 25%	
Total	100%
Limestone 6 ft. above base	
Quartz	48%
Feldspar	52%
K-feldspar (mostly microcline), 65%	
Sodic oligoclase, 20%	
Indeterminable, 15%	
Total	100%
Limestone 8 ft. above base	
Quartz	72%
Feldspar	28%
K-feldspar (mostly microcline), 45%	
Oligoclase, 15%	
Indeterminable, 30%	
Total	100%
Sandy layer 10 ft. above base	
Quartz	48%
Feldspar	52%
K-feldspar (mostly microcline), 55%	
Oligoclase, 15%	
Indeterminable, 30%	
Total	100%
Micaceous sandstone above limestone	
Quartz	39%
Feldspar	61%
K-feldspar (mostly microcline), 65%	
Sodic oligoclase, 12%	
Indeterminable, 23%	
Total	100%

the borders of quartz grains appear to be corroded. Bent muscovite flakes and barite crystals are also present. The heavy residue consists mostly of authigenic barite and a varied suite of rare minerals including indicolite.

One of the principal sandy interlayers in the limestone is found at the 10-foot level (loc. 9). It is 5 to 6 cm. thick, and can be subdivided into a number of extremely fine, contorted laminae (0.25-1 mm. thick) composed of silt, sand, clay, or dark organic matter. The general color of this layer is yellow buff. Under the microscope, the rock appears to be made of calcareous and sandy lenses which interfinger in a complicated way. Some of the curved layers suggest stylolites. The calcareous lenses contain around 76 per cent of calcite, the sandy lenses not over 15 per cent. In the calcareous parts, the familiar cyclic change of coarse light-colored calcite grains and fine dark paste is to be observed. Doubtful dark calcareous bodies, possibly organic, are also present. Some of them are dendritic, with dark material disposed between their branching layers. The calcareous parts contain also a number of isolated sand grains which generally are surrounded by a film of dark micro-crystalline calcite. It can not be said for a certainty whether these are incipient oolites or young algae. Lensing and cross-bedding are prominent and in places it appears as if certain calcareous layers had been pushed over sandy bands.

Limestone at Shuttle Meadow

General features. A limestone layer from 1 to 1 1/2 feet thick is found near the base of the lower Meriden dark shales of central Connecticut. It is, stratigraphically, the equivalent of the 15 feet of limestone of the Northford area. One of the best exposures can be seen in an old quarry at Davis Orchards, near Shuttle Meadow reservoir, 4 miles southwest of New Britain.

The rock is bluish-gray and weathers to a yellowish-buff color. In one instance, a band (5 mm. thick) of a light-colored, dirty-white calcite was observed. The limestone is layered and banded (1 mm. up to 2 cm. thick). This banding is usually extremely curved and contorted, even roughly parallel layers being bordered by crenulated planes.

There are practically no solution cavities (Plate XIII-A), this being a marked difference from the Northford limestone, which shows these cavities abundantly. Upon treatment with cold dilute HCl there is no formation of the thick layers of black and white foam observed in the Northford specimens. On the other hand, the rock etches into an amazingly irregular pattern of complicated curved thin bands marked by detrital impurities (Plate XIII-A) which contrast with the simpler protruding of sand grains in the southern facies of the rock.

The amount of insoluble residue is high, reaching 17 per cent. Most of it is fine dark-gray silt, in part apparently organic, but not bituminous (insoluble in ether).

Microscopic study. The rock is composed essentially of a mosaic of calcite re-crystallized to various degrees of perfection. The calcite varies from very fine (almost cryptocrystalline) and dark, to coarse and light-colored. There is some layering between these two kinds of calcite, but it is much less clear cut than at Northford. On the contrary, the two kinds of calcite intermix to a rather considerable extent, and are much less suggestive of depositional cycles (fine to coarse) than they are farther south. There is also no evidence of organic structures.

A remarkable feature of the rock is the large amount of fantastically contorted and curved planes marked by very thin layers of black, opaque, probably organic material. Sand grains are almost wholly concentrated in these dark layers, where they are imbedded in organic matter or dark, fine-grained calcite. The whole system of curved layers possesses only a very faint parallelism to the main bedding planes, and in many places the most curiously shaped pockets, lenses, and clusters are present. A fact to be noted is that these zones of disturbance often occur within the same layer of calcite (i.e., there is no morphologic difference in size, color, or shape of calcite grains on either side of the "break"). This may cast some doubt upon the interpretation which would consider them as desiccation marks, for indeed, in the case of the interruption of calcite deposition, a new cycle marked, first, by the formation of dark cryptocrystalline calcite would be expected. The possibility should not be ignored that, to a certain extent at least, the soft calcareous mud was disturbed by bottom currents which also moved sand grains to and fro and concentrated them into pockets. The existence of such currents seems quite probable from the cut-and-fill stratification observed not much higher up in the section. Finally, many of these features seem to bear some resemblance to stylolites.

The insoluble residue forms 17 per cent of the limestone. This is one of the very few Connecticut Triassic sediments which shows any appreciable degree of rounding, both in the light and heavy fractions. In the former, the feldspars are decidedly better rounded than the quartz, some of them perfectly so. The heavy minerals are also markedly rounded, some to an absolute degree of perfection, muscovite especially, and to a lesser degree tourmaline. Tourmaline, according to Freise, is the toughest of all minerals, and requires a considerable amount of abrasion before becoming rounded. This suggests a prolonged to-and-fro shifting of material in the lower Meriden lakes. The gentleness of these currents is seen from the perfect rounding of even small muscovite flakes and from the microscopic cut-and-fill stratification in some of the shales and siltstones.

Petrography of the Pyroclastic and Contact Rocks at Reed Gap

Location and Section

The Triassic sediments usually show some thermal alteration in the vicinity of igneous bodies. An excellent outcrop of the lower contact of the middle lava sheet is well exposed near the southern end of the trap quarry at Reed Gap on the Airline Railway (loc. 7). This locality is interesting in showing not only contact metamorphic effects, but also a layer of what may possibly be an altered tuff (?), separated by more than 16 feet of normal sediment from the lava body.

The following section is exposed (see Figure 15):

A—	Blue basalt and dolerite, microbrecciated near base	100 ft.
B—	Altered basalt, finely jointed, somewhat vesicular	1 ft. 6"
B—C	Contact zones; vesicular and amygdaloidal	6"
C—	Massive gray tuff (?)-like bed, layered near base	4 ft.
D—	Massive gray arkose, fine grained	2 ft.
E—	Laminated purple micaceous siltstone	6"
F—	Banded maroon siltstone	10 ft.
G—	Gray tuff (?)-like layer, obscurely bedded, base covered ...	2 ft.
H—	Talus	5 ft.
I—	Reddish purple arkose; top and bottom covered	1 ft.

Normal Dolerite and Basalt

The normal bluish dolerite and basalt (both varieties found in hand specimens from the talus) is exposed for 100 feet in a steep cliff. It is characterized by widely spaced (2-4 feet) columnar jointing which persists until within 1 1/2 feet of the contact. The lower 4 or 5 feet contain sparsely spaced, elongated vesicules, in the shape of vertical pipes or chimneys, 20 to 50 cm. long, and 2 to 5 cm. wide.

A specimen collected from 5 feet above the contact appeared to be normal, though rather coarse-grained basalt, with the hand specimen showing visible plagioclase crystals. Under the microscope (Plate XV-A) the rock proved to be a brecciated basalt, exhibiting a seriate porphyritic structure with phenocrysts of all sizes embedded in a matrix of smaller diabase fragments, and a dark isotropic mass. The rock consists of labradorite and augite, in places strongly replaced with calcite. There is much contorting and brecciation. The rock is almost a flow breccia.

The lowest 1-1 1/2 feet of the trap show a narrow columnar jointing (1/2 foot and less). The fresh rock is of a very pale bluish-gray color, which can be seen only in the core of the largest hand specimens, made possible by the narrow jointing. Otherwise, the basalt is weathered to a pinkish-buff color. The rock effervesces with cold HCl.

Under the microscope (Plate XV-B) the rock shows a vestigial diabasic texture and a subordinate porphyritic structure with larger feldspar phenocrysts. Extreme alteration and replacement have

taken place. The labradorite has been in many places replaced by calcite. The original ferromagnesian mineral (augite) has been entirely altered to brownish-red limonite and siderite. The rock contains large vesicles and amygdules (up to 3 cm. in diameter) filled mostly with carbonate, though, in some of them, a gossan-like box structure of limonite can be seen.

The line of contact between the lava and the underlying upper tuff-like layer is extremely sharp and well defined by a layer 0.5 to 1 cm. thick of amygdaloids or empty vesicles and limonite dust. This narrow contact zone is strongly oxidized. It may possibly represent a baked fossil soil.

Tuffaceous Layers

The two tuffaceous (?) layers at Reed Gap consist essentially of a colorless or pale-brown isotropic substance with a refractive index of 1.525± 0.004, in places greatly altered to calcite. Heating in a closed tube discloses practically no water (not over 1 per cent). This material can either be volcanic glass or an isotropic mineral with $n = 1.525$. The latter is not very probable, for only three or four rare and infrequently found minerals with unlikely paragenesis and different properties have such an index of refraction. If the isotropic material is volcanic glass, its probable composition on the basis of George's table will be andesitic.

Such a volcanic glass could have originated either in a tuff or in a lava flow. The following criteria bearing upon its possible origin are presented:

A—The lower contact of the volcanic material shows an intimate interlayering and interfingering with the underlying normal sediments. Such an intermixture is to be expected in the case of reworked pyroclastic material, but does not occur frequently at the base of a lava flow.

B—No vesicles, amygdules, or flow structures usually associated with lavas are present. The rock is very compact and has a tuffaceous appearance.

C—The presumed original vitroclastic texture is almost entirely obliterated by later alteration. This absence of positive identifying features such as glass shards or a tuffaceous relic texture prevents the definite labelling of the material as a tuff.

An intense search with the highest magnification possible revealed only three instances of minute textural features which appeared to be authentic curved angular glass shards. This can not lend enough support to the final interpretation of the material as a tuff. However, Ross says (1928, p. 146), concerning the obliteration of vitroclastic structures, "When the ash deposits fall on land and are reworked and redeposited, the characteristic structure may be completely destroyed."

The lower tuff-like rock separated by 17 feet of sediments from the lava is a fine-grained light-gray rock, very poorly and obscurely bedded (2-10 mm.). Only 2 feet are visibly exposed, the base of the

bed being covered by a talus mantle which persists for 5 feet. Hence, the thickness of this layer is possibly much greater than 2 feet.

Under the microscope (Plate XVI) the rock appears to be made mostly of isotropic glass, with a refractive index below 1.54, considerably replaced by calcite. There is a considerable amount of extremely small black opaque bodies which could not be positively identified. The estimated composition is:

Transparent volcanic (?) glass	50%
Black opaque specks (?)	20%
Minute mica flakes	6 to 8%
Quartz and orthoclase grains	2%
Secondary calcite	20 to 25%

The upper tuff (?) is a light-gray, fine-grained, and somewhat porous rock. Near its base, it gradually passes into the underlying arkose, the two rocks showing interfingering. The upper contact with the middle lava flow is unconformably abrupt. Under the microscope considerable alteration and evidence of contact action can be seen. The estimated composition is:

Volcanic (?) glass	25%
Magnetite	20%
Quartz and feldspar grains	15%
Micaceous material	1%
Calcite	40–45%

The glass has a refractive index of 1.525±. The impurities consist of quartz, orthoclase, and albite (Ab 95) grains. Graphic intergrowth between quartz and orthoclase can be seen in places. Some of the feldspars are entirely fresh, others are somewhat replaced by iron oxide. The absence of labradorite fragments suggests that this tuff is not connected with the overlying lava.

Gray Arkose

The upper and lower tuffs are separated by 12 1/2 feet of fine-grained arkose. The upper 2 feet of the arkose have been bleached by thermal contact action of the lava, the hematite having been transformed into magnetite.

This gray arkose (Plate XVII-B) is a massive unstratified rock with a very pale-purplish tinge. The constituents show poor sorting, but good sizing, the average particle being 0.08 x 0.12 mm. in diameter (range of size: 0.04 up to 0.5 mm.). The angularity is extreme. The absence of stratification is notable, even the mica flakes showing no traces of parallelism.

The composition is:

Quartz	41%
Feldspar	42%
Orthoclase, 50%	
Albite, Ab 95, 50%	
Magnetite, muscovite, biotite	15%
Calcite, tourmaline and minor constituents	2%

Among the constituents the quartz shows no strain shadows and almost no inclusions. It is probably of igneous origin. The potassium-feldspar is remarkable in that it is exclusively orthoclase and not microcline. This total absence of microcline has not been observed anywhere else in the Triassic rocks. Both the orthoclase and the albite are fresh.

The magnetite is extremely abundant. It occurs either as octahedrons or as irregular, sharp-edged grains, of all sizes from fine dust to particles 0.1 mm. in diameter. It is of secondary origin. The magnetite is mostly disseminated in the cement, but in some places may replace biotite or, rarely, the feldspar. This magnetite was formed through thermal contact action on the red iron oxide of the normal, unaltered red arkose. In spots a faint "running" of the magnetite and local secondary brownish and reddish strains due to recent weathering can be seen. A small amount of ilmenite, partly altered to leucoxene and anatase, is present.

A not very intensive replacement by carbonates can also be seen. Apparently both calcite and dolomite occur, with the latter predominating, and forming well-developed, in places saddle-shaped, rhombs. Some of the dolomite is related to ankerite. Different stages in this alteration process can be seen. The carbonates are interstitial and do not appear to replace any definite mineral.

The cement is scarce, most of the grains being in direct contact. It consists of a little kaolin and disseminated magnetite dust.

The heavy residue is given in Table 4C.

Normal Red Arkose

The normal red arkose (Plate XVII-A) below the zone of contact action is identical in all respects, save the form of its iron oxide, with the bleached and metamorphosed gray arkose.

The red shale contains some interesting calcareous concretions (Plate XVIII-B)), that have grown inside of the shale, pushing the bedding plane slightly apart.

CHAPTER V

STRUCTURE

General Features and Historical Review

The Triassic rocks of Connecticut form a homocline that strikes almost north-south and dips eastward, the average angle of dip being in the vicinity of 15°. On the east the Triassic is bordered by an immense fault, the "Great Fault", with an estimated minimum throw of 16,000 feet. Numerous faults break the Triassic homocline into a series of block faults. Most of these faults trend northeastward, and the throw of some of them reaches 3,000 feet.

The present attitude of the Triassic rocks is partly the result of the primary structure which they acquired during deposition, and partly the result of subsequent, post-depositional deformation. In the heroic days of geology the Rogers brothers thought that Triassic sedimentation was oblique and that these strata were laid down on the surface at the same angle with the horizontal which they possess today. These ideas were thoroughly disproved by W. M. Davis (1898), who, besides showing that Triassic rocks were of "normal" continental origin, also thought that their deposition took place in a downwarped trough. Emerson (1899) replaced this downfolded trough with a graben, downfaulted on both sides. Barrell (1915) introduced the concept that Triassic sedimentation took place in a wedge-shaped trough, subsiding on the east along the Great Fault with most of the sedimentary detritus coming from the Eastern Highlands beyond the scarp of the Great Fault. This view was supported by C. R. Longwell, by W. L. Russell, and by Foye (1922). It is also fully in accord with the results of the present investigation. An attempt to introduce the idea of a downbent canoe-shaped trough filling from both sides was unsuccessfully made by Roberts (1928).

The tilting and blockfaulting which followed the close of Triassic sedimentation have been interpreted by Barrell as due to the arching of the so-called Taconic geanticline between the Connecticut and New Jersey Triassic areas and to the collapse of the flanks of this arch. This view, with some modification, is generally accepted today.

The Great Fault has been held by Barrell and all subsequent investigators with the exception of Bain (1932) to be a normal fault. Bain considers it to be an overthrust. The results of the present study are entirely in harmony with Barrell's views.

Primary Structure of the Triassic Basin of Deposition

According to Barrell (1915), the Triassic rocks of Connecticut were deposited in a wedge-shaped trough, bordered on the east by

the Great Fault and in the west rotating downward around an axis located somewhere to the west of the present Triassic boundary. During the period of sedimentation the surface of the basin remained almost level, with a slight westward inclination. The bottom of the trough, however, as it was being more and more depressed, assumed a greater and greater eastward inclination. Hence the lower beds of the Triassic have a greater primary dip than the upper ones. Post-depositional tilting was superimposed upon, and added to, this primary eastward dip. It follows from this that the lower Triassic beds (which outcrop in the western part of the basin) should as a whole show a steeper dip than the upper beds (which outcrop farther to the east). In general this is true and was so reported by Davis. The difference in dip, however, is very slight.

Depression of the wedge-shaped trough proceeded along the Great Fault which was recurrently active during all of Newark time, and in fact controlled Triassic sedimentation. Fanglomerates along the fault, found as low as the uppermost New Haven beds, have been offered as proof of the existence of a fault scarp by Longwell (1922) and W. L. Russell (1922). Vein quartz pebbles coming from a large quartz lode along the Great Fault are found at all horizons of the Triassic, and this is offered by Russell as further proof that the Great Fault was already active in pre-Newark time, when the quartz lode was formed by magmatic waters circulating along the fault plane. The fanglomerates of the Great Fault point to such an intense erosion that a recurrent rejuvenation of the cliff-like scarp which provided them appears to be inevitable and essential for their existence.

Fanglomerates indicate an abrupt break in slope and a bold and rugged relief in the scarp region. They do not, however, suggest high relief and considerable altitude of the scarp. The relatively modest, and frequently small, size of pebbles and rock fragments in the fanglomerates suggests only a moderate relief. The largest boulders do not exceed 6 feet in diameter and these are only rarely found, most of the material being much less than 6 inches in diameter. There are none of the enormous boulders which mark the high scarp of the Sierra Nevada in Owen's Valley (Knopf, 1918). It is believed on the basis of this evidence that the altitude of the scarp may have fluctuated between 250 and 1,000 feet and probably never exceeded 1,500 feet. In this connection it may be said that, if erosion is sufficiently potent, a difference in relief of less than 500 feet between mountain top and valley floor is amply sufficient to provide boulders exceeding 8 feet in diameter (as will be shown in the discussion of the genetic significance of arkose deposits in the following chapter on climate).

As a further proof of the correctness of Barrell's hypothesis of a depressed, faulted, wedge-shaped depositional trough, the present investigation aims to offer a study of the relative thickness of strata

and the general mutual relationships between the Connecticut main area and the Pomperaug basin.

The Pomperaug basin represents an outlier of the main area, and, as shown elsewhere, can be correlated with it stratigraphically and mineralogically. Hence, an original westward extension of the Newark basin of deposition at least as far as South Britain is indicated. The New Haven arkose is approximately 800 feet thick in the Pomperaug basin. It is apparently from 5,500 to 6,000 feet thick west of Meriden. If these figures are plotted to scale and projected (Fig. 33) it is seen, first, that the thickness of the New Haven arkose in the immediate vicinity of the Great Fault may have reached 8,500 feet; second, that the basin extended at least 2 miles west of South Britain and, third, that by the end of New Haven time the angle between the sagging bottom of the trough of deposition and the surface of the ground was 3°.

If the relatively uniform thickness of the Meriden formation is superimposed upon this prismatic section and in addition a projection of the 4,000 feet of the Portland beds is drawn above it, then the following results are obtained: the maximum depth of the basin reached at least 16,000 feet, the maximum width was 35 miles or more, and the angle of sagging reached 5°. The basin, then, at the close of Portland time formed a wedge-shaped prism with a triangular section as shown in the middle part of Figure 33. This figure also shows how much of the original extent of the prism has been left untouched by erosion.

Sixteen thousand feet of thickness and 5° of primary dip are minimum figures which do not take into account the amount of Portland beds eroded away. Both the original thickness and the real primary dip may have been greater, with approximately an increase of 1° for each additional 3,000 or 3,500 feet of strata deposited along the Great Fault.

The sagging of the basin bottom was accompanied by a sagging and warping of the basin surface. As a whole, the basin was filled with sediments as fast as it sagged, and hence its surface was at all times nearly flat. However, during certain periods (especially during later Meriden time) structural warping of the surface appears to have been marked enough to dislocate the drainage and result in the formation of huge swamps.

The downward movement of the Triassic basin took place along the Great Fault gradually as a whole, but apparently in recurrent stages of variable intensity. The presence of a steep fault scarp, pointing to an active fault, can be traced(as shown by fanglomerates) as far back as the uppermost New Haven beds. The variable intensity of the movement along the fault is suggested by the preponderance of material of different degrees of coarseness at different horizons. Coarse material (conglomerates) suggests a steep topo-

graphy and hence a rejuvenated scarp and an active fault; fine material (shales and siltstones) conversely points to a lower relief in the source area, and hence to a scarp somewhat worn down by erosion and not rejuvenated with sufficient vigor. Basalt boulders in the fanglomerate above the upper lava sheet suggest a local retreat of the scarp somewhat east of the fault.

Conglomerates are abundant near the base of the lower New Haven arkose and again in the uppermost New Haven beds. It is tentatively suggested that, at the very end of the New Haven epoch, internal stresses become extremely pronounced and structural relief was sought in an exacerbation of the movement of the Great Fault, but was finally adequately provided only through the extrusion of the lower lava sheet.

The shales and siltstones of the Meriden beds indicate a dislocation of the drainage and, possibly, also a somewhat decreased supply of coarse material. The first item can be best explained by structural warping of the basin's surface. The second condition (i.e., decrease in amount of coarse material entering the basin) is somewhat debatable, for fanglomerates and coarse conglomerates are a feature of the Meriden beds near the Great Fault. Hence, a certain quantity of coarse material was still coming into the basin, although apparently in somewhat lesser amounts than in New Haven or Portland times. This coarse material, however, did not get transported far away from the vicinity of the Great Fault.

The real displacement of the Great Fault during Triassic deposition cannot be calculated exactly. As pointed out by W. L. Russell (1922), this displacement may have easily been differential on both sides of the fault, and hence would have comprised not only the 16,000 feet of the Triassic strata untouched by erosion plus the unknown amount of eroded strata, but also a certain amount of elevation suffered by the upthrown crystalline block east of the Great Fault. In other words, the Eastern Highland block may have been elevated more than the Triassic basin was depressed. This view finds supporting evidence in the composition, mineralogy, and total volume of the Triassic beds: most, if not all, of the Triassic sediments appear to have been derived from a source area extending not over 5 to 8 miles eastward of the fault, but this block, 5 miles wide and 3 miles high, appears to have been sufficient to furnish only between 50 and 65 per cent of the total volume of the sediments of the Triassic basin. It is suggested, to account for this, that a differential movement along both sides of the fault plane appears to be the most likely explanation, with probably an uplift of approximately 22,000 to 25,000 feet on the eastern side, corresponding to a depression of 16,000 feet on the western. This would account not only for most of the total volume of sediments of the Triassic basin but also for the steepness and almost constant rejuvenation of the fault scarp east of the fault.

Barrell, Longwell, W. L. Russell, and the present writer consider the Great Fault to be a normal fault. Bain (1932), on the basis of his work in northern Massachusetts in the Mt. Toby region, interprets it as a reverse overthrust.

However, an examination of the Mt. Toby area showed that the major structure of the region is in no way different from that of Connecticut (i.e., a normal fault) and that the peculiar sculpturing which caused the Mt. Toby topography is apparently due to differential erosion along a fault zone.

Post-Depositional Deformation

A considerable increase in dip at many places in the Triassic beds close to the Great Fault suggests that movement along the fault plane took place even after the close of Triassic sedimentation. The main post-depositional deformation, however, as interpreted by Barrell, seems to have been due to a tilting of the Triassic prism and its breaking into a series of fault blocks by a large number of faults, usually trending from northeast to southwest. The amount of tilting, as represented by the visible dip minus a primary dip of at least 5°, is not very high: from 7° to 10° only.

It is probable that tilting and downward blockfaulting went along simultaneously. Figure 33 shows schematically the amount of uptilting necessary to bring the present eroded surface of the Triassic parallel to the horizontal. Such a tilting implies an upward movement of approximately 15,000 feet in the Pomperaug basin area and a subsequent down-dropping of the same magnitude following blockfaulting.

Barrell explains the tilting as due to the arching of a geanticline between the Connecticut and New Jersey Triassic areas. This hypothesis of the Taconic geanticline has been generally adopted with only slight modifications by other students of the problem; it appears to be entirely possible, but can not be definitely proved.

The collapse of the wings of the arch is said to have provided the down-faulting which broke the Triassic prism into a series of fault blocks. These blocks have been described in detail by W. M. Davis. The displacement of some of the larger faults bordering the fault blocks reaches 3,000 feet. These numerous faults are marked on the surface by the displacement of the outcrops of the lava sheets. It is almost impossible to follow in the field the faults within the area of the Triassic sandstones. However, sedimentary analysis shows that in the vicinity of the faults considerable amounts of calcite and especially barite are present. It has thus been possible to project some of the larger faults into the sandstone areas on the basis of the relative abundance of barite (as for instance at loc. 15).

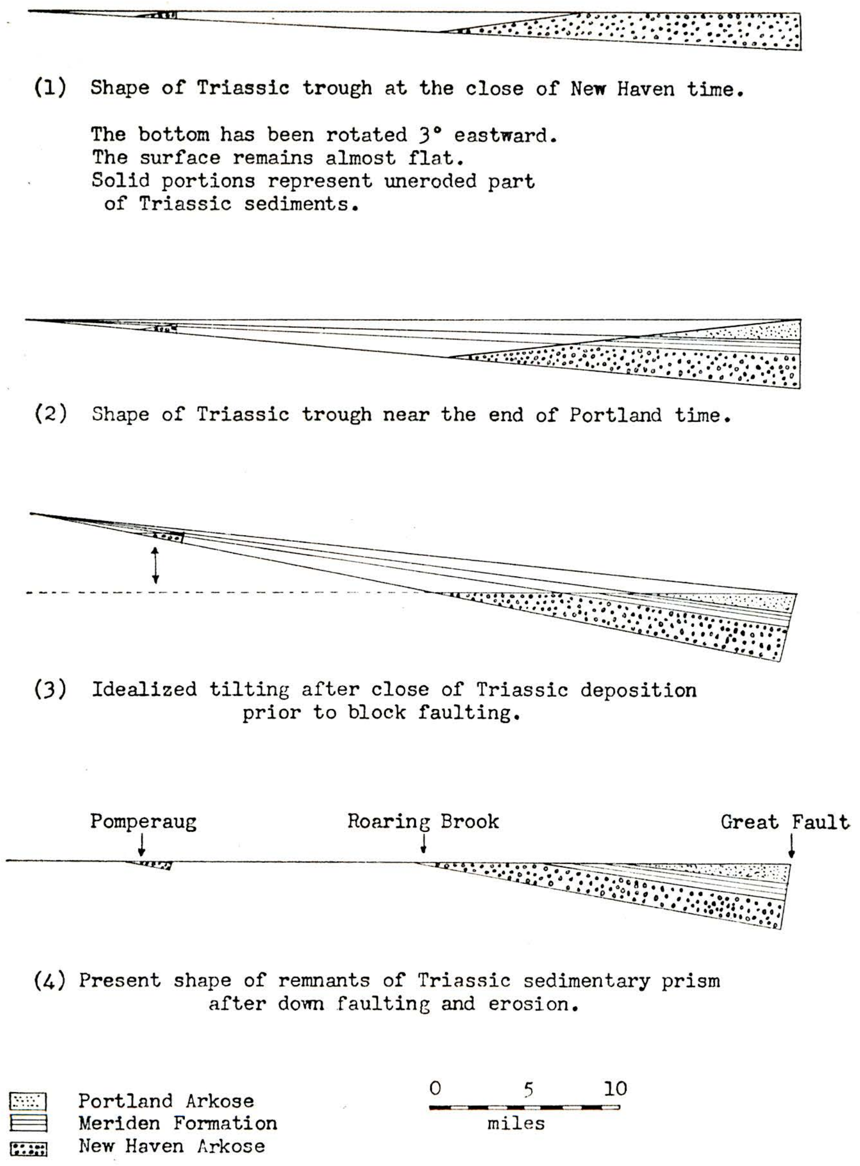


Figure 33. Development of the structure of the Triassic basin of Connecticut.

There is some doubt as to the primary attitude of these transverse and oblique faults. From the examination of the fault planes where they are well exposed, such as at Hanover pond, south of Meriden (Plate XXIV-B), or at locality 17 on Shepard Avenue,

Hamden, and from the data published by Longwell (1922) on the faults of the Saltonstall tunnel, it appears that these faults dip to the west with the downthrown side also to the west and, hence, are to be considered as normal faults. Barrell, however, has suggested that the present attitude may be due to rotation of the fault planes caused by tilting, and that the original fault planes may have been vertical, or even dipped east, i.e., that these faults were reverse faults. The fact that at some places the present and westward dip of the faults is in the vicinity of only 70°, however, would not be in harmony with the concept of an original reverse dip.

CHAPTER VI

CLIMATE OF THE NEWARK EPOCH

General Considerations

Definition of Terms

It appears desirable to preface a discussion of the climate of the Newark epoch by an exact definition of the terms arid, semi-arid, and humid. These terms can be made to possess a definite quantitative significance. This has been done by geographers and climatologists. Köppen and Leighly (1926) have developed equations to show the absolute precipitation that is characteristic of an arid, a semi-arid, a sub-humid, and a humid climate at different temperatures and under various systems of precipitation (uniform, rainy winter, rainy summer).

No such standardized usage exists among geologists. The term semi-arid, especially, is often used rather loosely. At best, it appears in the past to have been tacitly assumed to mean low annual rainfall with marked seasonal distribution. Often it does not mean even that, but rather answers to the personal ideas of a particular writer as to what a semi-arid climate should be. Regions with a low rainfall have been indiscriminately assigned to a semi-arid climate regardless of temperature, and regions with a dry season have suffered the same fate, regardless of absolute rainfall. For instance, some of the Brazilian highlands with a seasonably distributed rainfall of over 35 inches (and a rather moderate temperature of only 66° F.±), and certain parts of Wyoming, with a low temperature of 37° F. and a subuniform precipitation of 18 inches (a climate like that of eastern Sweden or Finland) have both been described in the geologic literature as semi-arid or even arid regions. The western slope of the Sierra Nevada, a decidedly humid country, especially in its central and northern portions, has been referred to as semi-arid.

To avoid such errors and the resulting confusion, it seems highly desirable to adopt the quantitative procedure of the climatologists. The climatic terms, arid, semi-arid, and humid, generally correspond to the desert, steppe, and forest belts (Russell after Köppen, 1926). Each of these zones is characterized by a certain amount of soil moisture constituted by the relation of evaporation to precipitation. Both plant growth and chemical action in the soil depend upon this. To assign a climate to one of these groups, a certain precipitation, depending upon the mean annual temperature, will have to be present. This necessary amount of rainfall will vary according to the character of its distribution. It will be smallest if most of the precipitation comes down during the winter (Mediterranean type), for evaporation will be lowest during the cold season. Conversely, it will be

highest with a rainy summer (monsoon type), for then evaporation is highest. It will be intermediate with a uniform or sub-uniform type of rainfall.

These relationships have been thoroughly analyzed by Köppen (1930 edition) and the results summarized in a series of very simple formulas. These equations serve to calculate the absolute precipitation characteristic of a desert, a semi-arid, or a humid climate at different temperatures and under various types of precipitation. Leighly has expressed these equations in graphic form and made them easily available to American readers.[8] The terms arid, semi-arid, and humid are used in this paper in Köppen's sense. As an illustration, in central and south-central California, a region with a Mediterranean type of precipitation (rainy winter) and a mean temperature of 60° F., desert regions will be characterized by a rainfall of less than 9 1/2 inches, semi-arid ones by a rainfall of between 9 1/2 and 16 inches, and sub-humid and humid ones will have a rainfall in excess of that figure. The dividing line between a sub-humid and a definitely humid climate under those given conditions has been set at 30 inches by Professor Huntington (personal communication of May 7, 1935).

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[8] Leighly (1926, p. 62):

The following table presents the critical values used in the case of the three main classes of seasonal distribution of rainfall. In the formulae, Ns represents the mean annual precipitation in centimeters on the moister limit of the steppe, i.e., the boundary between steppe and forest climates; Nw is the mean annual depth of precipitation on the moister limit of the desert, i.e., on the boundary between desert and steppe; t, the mean annual temperature in degrees Centigrade:

For stations with:

	Ns=	Nw=
Uniform distribution of precipitation throughout the year	t+33	t+16-½
Summer rain, winter drought	t+44	t+22
Winter rain, summer drought	t+22	t+11

When the temperature values are changed to the Fahrenheit temperature scale and the inch scale (5 cm. equaling 2 inches) for depth of precipitation, the relation, of course, is not so simple and the values above become the following, in which tF represents temperature in degrees Fahrenheit, and Ns and Nw are expressed in inches.

For stations with:

	Ns=	Nw=
Uniform distribution of precipitation throughout the year	$\frac{tF+27.4}{4.5}$	$\frac{tF-2.3}{4.5}$
Summer rain, winter drought	$\frac{tF+47.2}{4.5}$	$\frac{tF+7.6}{4.5}$
Winter rain, summer drought	$\frac{tF+7.6}{4.5}$	$\frac{tF-12.2}{4.5}$

History of the Problem

One of the first modern interpretations concerning the probable climate of the Newark epoch was given by I. C. Russell. From a study of the red soils of the southern United States and the western slope of the Sierra Nevada, and from occurrences of red soils abroad, he concluded (1889, p. 46) that

> "The red rocks of the Newark system and of the Rocky Mountains Red Beds were formed from the debris of lands that had been long exposed to the action of a warm, moist atmosphere."

Russell's views were accepted by Davis, who likewise ascribed a mild climate to the Connecticut Triassic (1898, p. 39). A heavy rainfall was also postulated by J. D. Dana, with the possibility of cold periods and even temporary glaciation (1883, p. 385; "the era of the Red Sandstone was one of great precipitation"). These classic American views were at variance with hypotheses developed on the other side of the Atlantic. Aridity for the Triassic was accepted by European workers.

Barrell departed from the path followed by Russell, Dana, and Davis and ascribed a semi-arid climate to the Newark epoch. He compared the sedimentation and climate of the Triassic with those prevailing at the present time in the Great Valley of California. Many of Barrell's ideas are well supported by facts. They have been most convincingly presented (1908, p. 183; 1915, p. 30). As a result the theory of semi-aridity was adopted by the majority of American geologists.

Barton (1916) attempted to reconcile the views of Russell and Barrell by explaining that while the source detritus of the Triassic was formed under humid conditions, its deposition followed later when temperate conditions gave way to semi-aridity and erosion superseded residual accumulation. This explanation, which had been invalidated[9] by Davis as early as 1898 (p. 39), apparently did not satisfy either Dorsey (1925) or especially Raymond (1928). The latter again proposed for the Triassic a warm and very humid climate. Raymond's ideas have not been very widely accepted as yet, although many of his arguments are difficult to refute.

This introduces the crux of the problem, and explains why the discussion between the followers of the theory of semi-aridity and the adherents of a uniformly very humid climate has been so unsatisfactory so far. The facts are that an impartial review of the statements made by either side show a curious mixture of weakness and strength. Some of the arguments are almost irrefutable. Other arguments are hardly tenable or downright erroneous. The impression arises that there is some truth in both and that the real truth lies in neither.

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[9] Furthermore, a simple quantitative check on a volumetric basis shows that assuming a rather high thickness of 50 feet for the "source detritus" the filling at one fell swoop of a Triassic trough only 20 miles wide and 8,000 feet thick would require a source area 3,200 miles wide, a fantastic absurdity.

Semi-aridity vs. Humidity

The main arguments advanced by Barrell and other supporters (Glock) of the theory of semi-aridity are as follows:

1) Arkose deposits containing fresh feldspars are indicative of rigorous climatic conditions.
2) Red beds can be formed best in regions where the absence of vegetation precludes reduction of the red ferric oxide. This is supported by many instances where red beds are associated with large deposits of salt and gypsum.
3) Mud cracks, rain pits, footprints, and other desiccation marks indicate a sub-arid climate.
4) Fanglomerates, as defined by Lawson, are a feature of arid (or semi-arid) regions.
5) The fauna and flora of the Triassic can be interpreted as those of an arid or semi-arid region with isolated, intermittent water bodies. The bipedality of the dinosaurs and the general absence of animal and plant remains specifically suggest a desertic environment.
6) Glauberite, gypsum, and halite form at the present time in Death Valley. The presence of their crystals or casts in the Triassic beds is a strong indication of aridity.
7) The finer-grained sediments (shales, clays, and matrix of coarser clastics) are, after Barrell, of critical significance: decomposed and leached, pale-colored material indicates a humid climate while red and undecomposed material points to aridity or semi-aridity (Note: This color scheme is a very critical point and unfortunately it has been invalidated by modern work on chemical weathering).

The arguments of Raymond run in the opposite direction approximately along the following lines:

1) Red soils at the present time are forming not in semi-arid areas, but in warm and humid regions. There is no convincing evidence to prove that the red detritus will be reduced upon deposition in a humid basin.
2) Fresh feldspar may have been supplied by erosion from "deep down" (if steep-walled canyons were a feature of the country. P. D. K.).
3) Sedimentation of such an enormous thickness of sediments suggests large volumes of water pouring into the valley.
4) The fanglomerates are really consolidated screes (Note: This is not correct. P. D. K.).
5) The fauna and flora are difficult to interpret as belonging to a semi-arid climate.
6) There is no evidence of eolian action.

7) Coarse conglomerates and barren mudflats (showing desiccation marks) should not be impossible in a humid climate if erosion is sufficiently rapid.

The territory of the United States possesses climatic provinces ranging from extremely cold to sub-tropical and from desertic to ultra-humid. It does not, however, contain rugged mountain ranges eroded under humid tropical conditions.

To a geologist well acquainted with the geomorphology and recent sedimentary processes of the North American continent the ideas of Raymond will appear interesting, possibly somewhat disturbing, but on the whole decidedly unconvincing. On the other hand, the theory of semi-aridity seems at first sight to be well supported by easily observable phenomena in the arid and semi-arid Southwest. Glock pointed out that all the features of the Triassic can be duplicated in the semi-arid deposits of the Southwest "save the red color". This last point, however, presents a formidable objection, and a hypothesis to be considered valid must account for all the facts without a single exception. Other difficult facts, not known when Glock wrote, have been brought to light by the present investigation.

Summary of the Sedimentary Record

The sedimentary record of the Connecticut Triassic has been described in the chapters on Stratigraphy, Petrography, and Structure. A brief summary of the facts, inasmuch as they affect paleoclimatic reconstruction, follows:

1) More than 15,000 feet of coarse, angular arkose deposits present, with an abundance of fresh feldspars and other chemically unstable minerals. Most of the material of local origin. Conglomerates present throughout whole section. Fanglomerates along eastern border visible in upper half of section and probably also present at much lower horizons.

2) Prevailing primary red color of sediments. In places alternation of grayish and reddish arkoses, bright-red and maroon-colored finer-grained siltstones and shales. Abundance of fine red clay in matrix. Interlayering and interfingering of black and red shales. Dark shales blanket whole valley at certain horizons. Iron concretions present at various levels. The clay contains gibbsite.

3) Chemically unstable minerals such as feldspars and biotite, *coming from the same source area* may show differential weathering which can be seen in every sample within the area of one thin section. In some instances less stable minerals such as orthoclase may be actually fresher than more stable varieties such as microcline.

4) Extreme abundance of desiccation marks (mud cracks, rill marks, raindrops, animal tracks, etc.).
5) Infrequent presence of crystals or casts of soluble salts (halite, glauberite, gypsum, anhydrite). Abundance of calcite as a cementing medium, but only near faults.
6) Fossil wood present through 15,000 feet of strata, although never abundant quantitatively. Carbonized wood remnants tend to form definite horizons of black or grayish arkose. Silicified wood present as isolated pieces through entire section.
7) Abundant megaphalous flora in the black organic shales. Outside of the black shales fossil plants not of typical xerophytic types, but rather large-leaved ones.
8) Extreme abundance of fossil tracks and almost complete absence of skeletal remains. Even outside of the black shales and their fish fauna, a notable proportion of the better preserved fossils is of aquatic origin. Large herbivorous forms present.

Each of these sedimentary features possesses some climatic significance. These features are generally, even if somewhat loosely, referred to as climatic criteria. The value of such criteria may be very diverse depending upon the method of their interpretation. A short discussion of such methods may well precede their application to the solution of the problem of Triassic climate and paleogeography.

Climatic Criteria and Their Value

Paleoclimatic work can be based either upon the organic or upon the sedimentary record. Fossils, notably specialized types, (if properly understood!) can be generally accepted as direct evidence for a certain environment. This, however, is not true at all in the case of inorganic phenomena, because sedimentary features are not the product of a given environment, but only of certain processes, and these processes may take place in several very different environments.

For instance, mud cracks really do not indicate semi-aridity. An entirely puristic interpretation of mud cracks would connect them only with dehydration of clays, which phenomenon for some clay types may take place spontaneously even under water (Jungst, 1934). A less extreme, but essentially conservative view is that mud cracks definitely prove only the sub-aerial exposure of a wet, muddy surface for a period which may not have exceeded twenty-four hours. Conservative interpretation can not proceed any further unless quantitative information is at hand as to the frequency and type of mud cracks in a given formation. Numerous mud cracks suggest a definite period of dryness, very abundant and *deep* mud cracks suggest a lengthy dry season. But none of these data can be legitimately used to infer the amount of rainfall during the wet season—that is, of

the real factor which determines whether the climate is arid, semi-arid, or humid. The dry season may last for nine months, but the rainfall during the remaining three months may exceed 70 inches (monsoon climate of India).

As another example it may be stated that deposition of soluble salts indicates only: a) concentration of water in a closed basin; and b) a certain rate of evaporation sufficient to precipitate the salts, depending upon the character of the original brine and its subsequent concentration. The essential requirement is a closed basin with no outgoing drainage, and not an arid climate.

Arkose deposits prove conclusively only that erosion of a granitic terrane and deposition of the debris are proceeding at a faster rate than the work of chemical decay. The rate of chemical decay may be very low and the erosion barely active, or the rate of decay may be extremely high, but the rate of erosion so rapid as to prevent decay from taking place. Topography again is just as important as climate, if not more so. Striated pebbles and surfaces, different types of cross-bedding, fanglomerates, all these features are the results of dynamic processes, which may take place for any one phenomenon in as many as half a dozen different environments.

These scattered examples, which will be discussed more fully later on, show that it is impossible to regard sedimentary features as absolute climatic criteria. They merely indicate processes, and it is up to the geologist to interpret under what conditions of climate and topography these processes may have operated.

This concept of dynamic process rather than of static environment, although absolutely fundamental, is of course very elementary. The writer would feel almost apologetic for bringing it up were it not for the fact that it has been consistently ignored, especially abroad. Confident and dogmatic statements as to the value of climatic criteria are much too frequently found in the literature.[10]

In conclusion it may be said that

1) Sedimentary features are criteria for a process and not for an environment.
2) A purely qualitative interpretation of sedimentary features is valueless unless reenforced by a conservative evaluation of their quantitative importance.
3) Structure and topography are just as important as climate in shaping sedimentary processes and probably are even more so.

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[10] As an example, Mortensen (1930, p. 481) approvingly mentions "the explicit definition of Kaiser, who emphatically said that the formation of gypsum is a positive sign of an extremely arid climate" ("die klare Aussage Kaisers, der die Ausscheidung von Gips ausdrücklich ein deutliches Zeichen extrem ariden Klimas nennt"). Four superlatives in a single sentence concerning a somewhat debatable question!

Genetic Significance of Arkose Deposits

Introduction

It will not be an exaggeration to say that a large number, if not the majority, of geologists usually associate arkose and graywacke deposits with a rigorous climate. Arkose deposits of any kind are generally connected with at least semi-aridity, and frequently with complete aridity or glacial conditions. Arkose deposits with very fresh feldspars are still considered by many a modern textbook as a valid criterion of a desertic environment.

This concept, which followed the classical researches of Judd (1886) and Mackie (1899), was best expounded by Barton (1916), who showed that arkose deposits can be divided into two classes—namely those formed under:

1) Rigorous (preferably desertic or glacial) conditions, and characterized by very fresh feldspars and other chemically unstable minerals (augite, biotite, hornblende, etc.).
2) Semi-arid or temperate humid conditions, and characterized by somewhat altered and decomposed feldspars.

Thus, Barton restricts fresh feldspars to a rigorous climate and fails entirely to list arkoses formed under extremely warm and very moist climatic conditions such as those present in the humid tropics. However, more than twenty years ago Iddings (1915) commented upon the prevalence of fresh rocks in the Dutch East Indies. Woolnough (1930) also noted the extraordinary vigor of erosive processes in the South Sea Islands and the freshness of the rock debris. The potency of erosion in the humid tropics has been emphasized by Sapper (1935a). Typical arkose deposits on a large scale were described from southern Mexico (Krynine 1935a). Other instances of the same kind can be found in the newer literature.

As a result of these latest discoveries it appears that the absence or deficiency of rainfall (and hence of potential chemical decay) is not the controlling factor in the formation of arkose deposits. What, then are the controlling factors?

Conditions under which Arkose Deposits Can Form

Theoretically at least, any sediment will be influenced by the conditions of its environment during the following three stages:

1) Erosion; i.e., breaking up of the parental rock, and loosening and removing of the fragments.
2) Transportation.
3) Deposition.

In the case of arkoses which are usually continental coarse clastics, the transportation is generally relatively short and the deposition is rapid. Hence, *as a rule*, arkoses decay but little in transport.

Also, they are covered up so rapidly as largely to eliminate the effect of unfavorable chemical influences active at the time and place of deposition. Essentially, then, we are concerned with the environment under which a granitic terrane can be eroded in such a way as to prevent the decomposition of the feldspars, and possibly of even the less chemically stable minerals such as biotite, hornblende, augite, etc.

It is obvious that an environment in which chemical decay is inhibited will be ideal for the formation of arkose deposits. Quite naturally the idea arose that arkoses were the product of a rigorous climate (desert, semi-arid, or glacial) where chemical decay was at a minimum.

The fundamental mistake in this generalization was that the rate of chemical decay was accepted as the controlling factor of arkose formation, instead of the more important factor of total amount of chemical decay suffered by the rock. For it is indeed a matter of elementary arithmetic to prove that 1 x 10 equals 5 x 2, and that a very high rate of chemical decay applied during an extremely short period of time will produce no more results than a very low rate of decay acting over a much longer period. Theoretically, then, arkoses can form under any kind of climate if erosion is sufficiently rapid and violent to break up the rock and remove the debris before it decays appreciably. The Tabasco arkoses and the observations of Iddings, Woolnough, and Sapper prove that this is not theory only. This statement is advanced, not as a new discovery, but as a fact which, unfortunately, has been consistently ignored by too many geologists.

The total amount of chemical decomposition to which a granitic terrane has been subjected, and not the rate at which this decay proceeds, will hence be the deciding factor in preventing or favoring the formation of arkose deposits. Arkoses are formed when feldspar-bearing rocks are eroded and deposited before their feldspars have time to decay. Hence, the two primary factors in the formation of arkoses are the rate of chemical decay and *the time during which this decay is at work.* The latter (duration of decay) is inversely proportional to the intensity of erosion. By erosion is meant the loosening and removal of fragments from the bedrock by any process whatever (mechanical disaggregation, hydration, hydraulic action, abrasion, collapse of canyon walls through undermining, etc.).

Now, both chemical decay and erosion can be subdivided into a series of separate factors.

Factors Controlling the Formation of Arkose Deposits

The two fundamental factors of chemical decay and erosion (or rather their respective rates) can be expressed in terms of climate and relief—i.e., rainfall and character of its distribution, tempera-

ture (maximum, minimum, and average), elevation, and angle of slope. These meteorological and topographic factors possess definite numerical values and can be subjected to mathematical treatment. Kerner-Marilaun has evolved formulas to indicate the specialized climatic conditions controlling the formation of laterite (1927), the Mediterranean terra rossa (1930), and mechanical weathering in deserts (1930).

In arkose and graywacke deposits the problem is much more complex, for these rocks can form in a variety of climates. The detailed character of the required meteorological data and the high number of variables involved, furthermore complicated by an equal number of unknown qualifying coefficients of their relative importance (at least for the time being), preclude the possibility of a satisfactory quantitative mathematical treatment.

Rate of Chemical Decay

The rate of chemical decomposition depends upon heat and amount of moisture. It is known (Robinson, 1932, p. 266) that the speed of a chemical reaction increases twofold with every 10° C. of increase in temperature. The influence of rainfall is quantitatively less well known, but to a large extent it is probably directly proportional to the total amount, at least up to a certain saturation point when rainwater is supplied faster than it can perform its chemical work. The influence of rainfall will also be modified by steepness of slope (faster run-off on a steep slope) and by the character of the drainage. In a close, saturated basin (swamp) chemical action will be less powerful than on a well-drained upland. Thus, chemical decay is most rapid and potent on a flat, well-drained upland in a hot and humid climate. The lateritized red savannas of the tropics are the best examples of this.

Rate of Erosion

Seasonal distribution of rainfall and a high and bold relief increase the rate of erosion. On the other hand, a cover of vegetation, a uniform distribution of rainfall, and a low relief tend to retard erosion. These negative factors will be considered first.

Factors Retarding Erosion. Vegetation depends directly upon climate, i.e., upon light, temperature, and rainfall. In general (Huntington, 1933), a sizable vegetation (that is, one sufficiently luxuriant to inhibit erosion) does not develop in regions where the average annual temperature is below 4 1/2° C. (40° F.). Nor do forests flourish in districts where the temperature of the warmest month falls below 14 1/2° (58° F.), when the climate is a seasonal one with severe winters (high latitudes), or conversely, where the warmest three months fail to average 10° C. (50° F.) if the climate is uniform (high altitudes in the tropics).

The amount of soil moisture necessary for plant growth will be proportional to the annual rainfall, subject to modification by the temperature, for the higher the temperature, the greater the evaporation.

The influence upon the vegetation of whatever moisture finally gets into the soil is a somewhat roundabout one. The main controlling factor is really a sub-uniform distribution of the maximum amount of rain during the growing season of the plants. An analysis of this factor is a hopelessly involved affair. It will suffice to say that the luxuriance of the vegetative cover will be roughly proportional to the average annual rainfall and its favorably uniform distribution.

Hence, a high temperature and a heavy rainfall will handicap erosion by fostering a luxuriant forest cover. This, however, is entirely true only on flat surfaces or on very moderate slopes. As will be shown later, a high rainfall on a steep slope may circumvent completely the inhibiting effect of any kind of vegetative cover. It appears, then, that *in the absence of topographic control*, a rigorous climate is much more favorable for the formation of arkose deposits than a hot and humid one.

A *uniform distribution of rainfall* will handicap erosion, for a vegetative cover adapts itself to the average rainfall of the country. Hence, in order to break through the vegetation and start erosion, cloudbursts well above the average precipitation are required. Such cloudbursts are a feature of regions with a seasonal distribution of rainfall, regardless of its absolute quantity.

A *low relief* obviously retards erosion.

Factors Favoring Erosion. Heavy rainfall, seasonally distributed. This can be subdivided into the following elements:

A) Cloudburst intensity, conveniently expressed as the maximum precipitation observed in a region during a thirty-minute period. Really destructive downpours usually do not last much longer, regardless of the character of the climate. The destructive effect of such a cloudburst will be a function of the difference between the precipitation during the cloudburst and the average precipitation to which the plant cover is adapted.

B) Frequency of cloudbursts. Potentially each downpour above the average has erosional possibilities. Practically only a fraction of the days with rainfall above the average will have a precipitation large enough to do some erosional work. This is not quite true of deserts where every rain results in erosion. When comparing the work done by the rainfall in an arid (or semi-arid) region with that produced in an extremely humid tropical region, it is well to keep in mind the following differences:

a) Cloudbursts in an arid region, literally coming out of a blue sky, remove the mantle of waste produced by mechanical disintegration. Their effect upon solid bedrock is generally slight.

b) Cloudbursts (or better, abnormally heavy rains) during the wet season of a tropical humid region may do the following work (subject to the presence of an adequate topography, as discussed later):

1) Break through the vegetation cover already strained nearly to the limit of its endurance by the soaking of the soil caused by the preceding normal or only slightly supernormal precipitation. This takes place especially along preferred paths of tiny depressions or incipient gulleys.

2) Remove the mantle of waste and denude the rock.

3) Attack the fresh bedrock either through direct hydraulic action or abrasion especially by undermining of canyon walls. Only first-hand experience can give an idea of the colossally destructive possibilities of ordinary rain water cascading down the steep slopes of a denuded canyon in the tropical jungle belt, after a really stiff downpour during the rainy season. The amazing recuperative capacities of tropical vegetation (which grows literally overnight) explain why such breaches are not permanent and why deforestation is prevented through the prompt re-establishment of vegetation between breaches.

c) In the permanently humid tropical rainforest the vegetation is so dense as to prevent normal rainwash and soil erosion. Nevertheless, even under such unfavorable conditions erosion may be extremely violent. These peculiar erosive processes of the permanently humid tropics have been described by Sapper (1935) and summarized by Krynine (1936) in the following way (p. 301):

"The supremacy of vegetation and of chemical decay is unchallenged in the flatlands. In the mountains, however, there is an eternal struggle between the forest and running water. The triple roof of the jungle disposes of the impact of the tropical rainfall as an eroding force. The force of this impact is otherwise terrific and plays havoc with unprotected soil. A considerable runoff however is inevitable, for the soil is almost always near its saturation point. As soon as the slope permits, the runoff unites in rivulets which take advantage of the slightest depressions to begin gulleying. Lateral erosion and spreading out is most effectively inhibited by the vegetation which holds the soil in a vise-like grip, but the vertical erosion downward (Tieferosion or Linearerosion) is possible. This vertical erosion is the main geologic process of the humid tropics, the fundamental feature which controls both geomorphology and sedimentation.

"Steep gulches and valleys soon develop, and the streams cut through the 20 foot layer of red soil into fresh, nonweathered bedrock. Through direct abrasion and hydraulic action the stream carves its bed downward without benefit of mechanical weathering as we know it. Small creeks are incised from 15 to 20 feet and some larger streams hundreds of feet into the bedrock. It is difficult to understand fully the erosive possibility of a

tropical mountain torrent without having seen it in action after a normal (i.e., terrific) cloudburst...... Even the violent erosive processes of the arid and semi-arid regions are weak compared with tropical erosion."

Such extreme erosive processes have also been described by Woolnough (1930) and by Robinson who states (1932, p. 66):

"The extent of erosion in the tropics and certain parts of the sub-tropics is scarcely apprehended by those who are only familiar with British conditions."

and furthermore (p. 64):

"Here (i.e., in the humid tropics) the rain occurs to a large extent in intensive falls of comparatively short duration,—as much as six inches per hour having been recorded."

It appears, then, that a rainfall occurring in cloudbursts will greatly favor erosion. The maximum destructive effect will take place either when the absolute precipitation is very low (little or no vegetation cover) or when it is extremely high (the vegetation cover is overcome by the sheer brutality of terrific downpours canalized down into ravines and canyons). The absolute amount of erosion (a function of the volume of water and the frequency of its application) is much higher with a heavy rainfall. Also the tropical seasonally humid regions are just as extensive as the desert or semi-arid areas of the globe, if not much more so. However, the arid regions have been much better studied and are much more accessible. This explains why the geological mind usually associates extreme erosion with arid regions and not with the humid tropics, as it really should be.

High and bold relief. This factor can be subdivided into two elements—namely, absolute altitude and steepness of slope.

a) Elevation of ridge tops over valley floors. The velocity of falling water will be proportional to the square foot of the elevation.

b) Steepness of slope. It is obvious that a steep angle of slope will promote erosion by giving less of a foothold to vegetation and also by reducing the distance to be travelled by water before it reaches the stream gradients. Both slopes and gradients are usually closely associated in character depending upon the stage in the erosion cycle. If the angle is 0, then its influence upon the velocity of water coming down it will be proportional to the value of the sine (at 90°, sin = 1, and water falls unimpeded due to gravity; at 0°, sin = 0, and there is no movement of water at all, with all possible variations within these limits).

Inasmuch as the abrasive power may be equal to the square, cube, or even sixth power of the velocity, the influence of relief will be proportional to a certain function of the square of the sine of the angle of slope rather than to the simple sine. This is in accord with Barrell's statement when he said in 1917 (p. 757):

"Denudation in the same rock formation varies with the slope and probably at a somewhat higher rate than the change in the angle of slope."

A study of the curves which express the change in the angle of slope (straight line), the sine of the angle (sinusoid), and the square of the sine (concave sinusoid) show that for the last curve (which probably is also the erosion curve) the change is much more rapid than the increase in slope between the angles of 10° and 60°. Apparently, below that minimum steepness (10°) not enough momentum is available, and above 60° the slope for all practical purposes behaves like a vertical cliff.

This last factor (steepness of slope) is easily the most fundamental one. A very steep slope will accelerate erosion beyond all belief, nullify the effectiveness of the vegetation cover, and make chemical decay inoperative. The absolute elevation need not be very great: it is the ruggedness that counts. In southern Mexico (Krynine, 1935a, p. 358) the ridge tops are only 500 feet above the valley floors and only 1,000 feet above sea level, but the violence of the erosive processes in this region is unparalleled (Plate XXVII).

A rugged relief may result in the formation of arkose deposits even in hot regions of heavy and constant precipitation, provided the rainfall occurs as sharp and violent cloudbursts (as it does in the tropical rainforest). This has been noted by Sapper (1935) and by Krynine (1936):

"Hence the factors typical of the mountainous regions of the tropical rainforest belt and which control both sedimentation and the sculpture of land forms are: deep chemical decay, absence of mechanical weathering as we know it, almost complete absence of rainwash and lateral erosion and an extraordinary development of vertical erosion acting on fresh bedrock along the floors of extremely steep canyons.

In the field of sedimentation an apparent paradox can be seen immediately: whereas most of the region is blanketed by a thick layer of red soil and laterite this layer is not subject to erosion. Instead the sedimentary detritus is furnished almost entirely from the stream beds cut into fresh nonweathered bedrock. Furthermore this detritus is produced not by mechanical weathering, but by direct fluvial erosion. Sapper mentions that tropical mountain torrents usually carry boulders 3 feet (1 m.) in diameter. The writer (Krynine) has seen angular boulders 8 feet in diameter carried by the torrents of Chiapas in Southern Mexico.

It follows that in the humid tropics the sedimentary detritus coming from a steep mountainous region covered by a virgin rainforest and blanketed with a layer of red soil or laterite will consist mostly not of fine grained, deeply weathered material but of coarse, nonweathered sand, gravel and cobbles. The fate of this coarse nonweathered material will vary according to the length of the supplementary transport outside of the mountain area. If deposition takes place on a piedmont in the immediate vicinity of the mountains, then large fans consisting of coarse arkosic material are formed. Such deposits may be marine if rivers from the mountains empty directly into the sea (as on tropical islands). If, however, the coarse material is subject to lengthy transport along the course of a large stream, it is abraded, ground into fine sand and silt and after further dilution with clay matter it finally forms the fine silty deposits of the coastal plains of the great tropical

rivers. Our present ideas of tropical sedimentation, having been based on the study of such large rivers as the Amazon, are restricted to this type of fine silty deposits. To this old concept we must add the possibility of coarse arkoses and conglomerates forming in the proximity of a mountainous mass. Such coarse deposits of the humid tropics will hardly be distinguishable as to freshness and size grading from similar deposits of semi-arid or even arid regions."

Horizontal vs. Vertical Erosion

The different factors and processes discussed above, which combine to produce physical erosion, can be classified under two basic types of erosion[11] as shown on Figure 34.

1. *Horizontal erosion*, i.e., lateral removal of *soil mantle* by wind, rainwash or ice. This is the common process observed in the temperate zone under conditions of gentle relief. This type of erosion may be greatly inhibited by a vegetative cover.

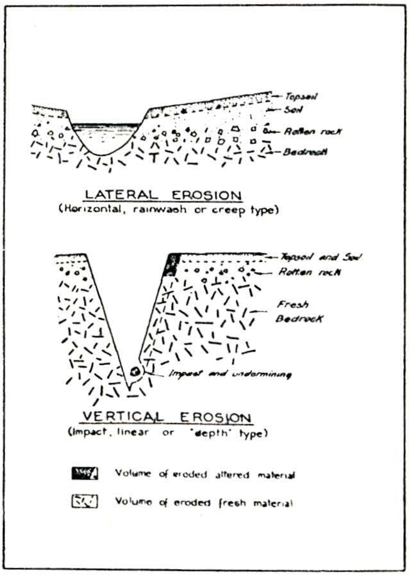

Figure 34. Comparison of lateral and vertical erosion.

2. *Vertical erosion*, i.e. deep linear erosion of both soil mantle and *fresh bedrock* by impact and undercutting of canyon walls in regions of steep topography and high rainfall, especially if seasonally distributed. This type of erosion may not be inhibited at all by a vegetative cover. The Triassic arkoses of Connecticut were formed by physical vertical *erosion*.

[11] The following discussion of physical erosion is given by P. D. Krynine in Lecture 9 (Period XXI) of the mimeographed syllabus of his course on "The Petrography of Oil Reservoirs" at the Pennsylvania State College (1944-45 edition):

(2) *Physical horizontal erosion of unconsolidated regolith* or soil mantle. (Shallow sheet, lateral, surface or rainwash erosion). Results in 100% removal of loose material but is very ineffective against hard, consolidated bedrock.

AGENT	
Gravity	Creep and talus.
Wind	Deflation (operates only on weak unconsolidated material).
Ice	Ablation or exaration.
Water (little)	Creep and rainwash—a slow process through a soil mantle held together by vegetation.
Water (more)	Mudflow.
Water (much)	Sheetflood.

The rainwash or horizonal or surface type of erosion is the common denudation process in temperate humid regions of low or moderate relief and as such is described in all textbooks. It is a moderately effective process although a slow one. It can be compared to the removal of pancakes one after the other from a stack of pancakes.

(3) *Physical vertical erosion of both soil mantle and solid bedrock* (deep, line or impact erosion). Extremely effective in removing any kind of material.

AGENT	PROCESS
Ice	Glacial corrosion and ice plucking (ice quarrying).
Water	Linear erosion through impact, undermining and flushing (hydraulic quarrying).

The vertical or impact type of water erosion is especially active in hilly regions of steep (not necessarily high) relief and heavy rainfall. Found both in the temperate zone and particularly in the humid tropics. Proceeds through impact of boulders at bottom of steep V-shaped canyons which act as battering rams; undermining and collapse of canyon walls follow, thus introducing large amount of fresh debris from unweathered bedrock into detritus. Regolith and soil in very steep canyons may contribute less than 20 per cent to detritus; bedrock, the other 80 per cent. Vertical erosion can be compared to the slicing of a cake (soil is icing).

LOCI OF ACTIVITY AND TIME-SPACE RELATIONSHIP DURING EROSION

Maximum chemical erosion takes place on moderately dissected and well drained surfaces in regions of high rainfall.

Maximum physical erosion takes place in regions of steep and rugged relief also in regions of high rainfall, although for limited periods of time physical erosion may be prominent in arid regions.

Lateral physical erosion is strongest on moderate to steep slopes developed on weak materials (soils or unconsolidated bedrock) unprotected by vegetation. A balance exists between the formation of soil by weathering and its removal by erosion. Climatically high rainfall promotes rainwash but it also increases at an even faster rate the thickness of vegetation which holds the soil in place. If chemical weathering outstrips lateral erosion the depth of soil increases; if a balance is maintained the land surface wastes gradually through rotting followed by removal; and finally if erosion becomes accelerated (usually through loss of vegetation cover due to defores-

tation, forest fires or droughts and superposition of aridity and semi-aridity) then the soil mantle is very rapidly stripped away. However, after this fast spurt, erosion may become very slow as soon as the solid bedrock is reached unless this bedrock consists of weak, unconsolidated sediments. The rapid and potent erosional processes in many of the younger present day deserts are due to the stripping of soil mantles developed during the pluvial periods of the Pleistocene and this apparent erosional efficiency will come to an end (as it did in many of the older deserts) as soon as solid bedrock is reached.

Rejuvenation through increased relief usually promotes a combination of vertical and lateral erosion.

Vertical physical erosion is strongest in sharply dissected and steep youthful regions with relatively flat interfluves held by vegetation so as to keep up the steepness of canyon walls. Vertical erosion is not inhibited by vegetation since the locus of maximum activity is at or near the bottom of V-shaped canyons; hence this erosion is promoted by rainfall almost in a direct ratio or even better, with no antagonistic retarding effects due to vegetation. Vertical erosion probably supplied the bulk of sediments in the periods of strong deformation (orogenesis) and much if not most of the detritus during the period of moderate (geosynclinal) deformation.

Topographic Control and Seasonal Rainfall, as the Real Factors in Arkose Formation

The enumeration of the factors controlling the formation of arkoses makes a somewhat formidable list. To a certain extent this may prove useful in showing the complex relationship of climatic and topographic factors and of their component elements. Its main purpose is to bring to the attention of the geologic mind the necessity of adding two new major factors to the time-honored twins of temperature and absolute rainfall. These new factors are topography and periodicity of rainfall.

The profound influence of these factors is illustrated in southern Mexico, in a region with an annual rainfall of 100 inches and up (seasonally distributed) and a mean temperature of over 80° F., in which fresh unweathered arkoses originate in youthful mountainous districts and are laid down in basins on the flat savanna, side by side with deeply decayed red soils of local residual or detrital transported origin.

Practical Applications

The geologic column boasts of an extremely large number of so-called arid or semi-arid deposits, a number out of all proportion to the relative areal distribution of humid and arid sedimentation basins at the present time. On the contrary, a very high proportion of the large contemporaneous accumulations of continental sediments is taking place in humid piedmont basins, from detritus derived from mountain ranges with a very heavy rainfall. Very likely a careful reinvestigation of the deposits ascribed in the past to deserts and semi-arid regions will show that a large proportion of those not

definitely connected with salt or gypsum are of humid, or even more probably of ultra-humid (seasonal) origin. In such work the application of the concepts of topographic control and seasonal precipitation will be of great help. It has been shown that the formation of arkose deposits is controlled by rainfall, temperature, seasonal distribution of rainfall, and topography. Hence, if some of the factors are known, much concerning the others may reasonably be inferred. For instance, a known low relief genetically associated with arkose deposits will point to a rigorous climate; conversely, a high temperature and heavy precipitation (as indicated by fossils) also genetically connected with arkose, will strongly suggest a bold and rugged topography. High relief alone will suggest a series of possibilities. Its recognition will be useful in that it should prevent the attempt to connect an arkose deposit with semi-aridity without having on hand stronger supporting evidence than the mere fact of the arkose's presence.[12]

Finally, a systematic use of the two concepts of topographic control and heavy seasonal rainfall when attempting to interpret deposits of the geologic past may be extremely useful in explaining obscure and apparently mutually excluding evidence. For instance,

[12] The following classification of arkose deposits was worked out by P. D. Krynine in 1943 and will be published in detail in the near future. At the present time a brief treatment of this problem can be found in the mimeographed syllabus outline of a lecture presented by Krynine on June 2, 1943, before the Pacific Section of the American Association of Petroleum Geologists at Los Angeles.

The classification of arkoses is as follows:

A. Non tectonic arkoses: residual and "blanket" types not connected with a major orogenic period.
   1. Residual arkoses—thin "granite wash" of the Mid Continent and most "basal" arkoses.
   2. Glacial arkoses—Pleistocene drift.
   3. Desertic arkoses—Very problematic types, possibly the Torridonian sandstone (?).
   4. Marine modification of preceding types—basal Ordovician of Canada.

B. Tectonic arkoses: accumulated and "thickly prismatic" basinal types, directly produced by intense orogenic deformation.
   1. Structural classes
      a. Connected with folding (Pennsylvanian of Colorado, some Tertiary of California).
      b. Connected with faulting (Triassic of Connecticut and Pennsylvania, some Tertiary of California).
   2. Climatic classes
      a. Tropical humid and savanna climates (Triassic of eastern United States, Chinle, Tertiary of California, Recent of Central America).
      b. Two-province type (humid in area of erosion, semi-arid in area of deposition. Recent of California).
   3. Marine modification of preceding types (2) and (3). (Thick granite washes of the Mid Continent type.)

why are fresh arkoses interbedded with red argillaceous siltstones on one hand and mud-cracked black organic plant-bearing shales on the other? Such an association becomes easily understandable if the locus of sedimentation or "environment" is assumed to be *a humid tropical savanna in the immediate vicinity of a rugged area.* In the following pages an attempt will be made to show how the application of these concepts enables us to draw a coherent and reasonable picture out of the welter of apparently conflicting evidence found in the Triassic sediments of the Connecticut Valley.

Genetic Significance of Continental Red Beds

Origin of the Red Color

The red color of sediments may be due to:

1) Presence of inherently red minerals (such as pink feldspars).

2) Impregnation with red iron pigment which may have the following origin:

- a) Primary (pre-depositional), due to subaerial weathering.
- b) Post-depositional, but essentially penecontemporaneous with deposition, also due to sub-aerial decay.
- c) Diagenetic, due to deep-seated process (dubious outside of sideritic layers).
- d) Post-diagenetic due to weathering of outcrops.
- e) Second cycle or secondary (reworked)

In the first case the red color is usually caused by the abundant presence of fresh or only slightly weathered pink feldspars. In the latter instances, the red color is due to coating of mineral grains or to the dissemination throughout the rock (or at least the matrix or cementing medium) of a red pigment consisting of ferric oxide (Fe_2O_3), preferably dehydrated or anhydrous.

The chemistry of the iron oxides has been the subject of a very prolific literature. At the present time the following facts appear to be reasonably well established:

Iron is soluble either as a bicarbonate, a sulphate, or an organic compound; after solution it may remain in the soil, or be transported far away, or be deposited close to its source. The greatest concentration takes place in the regolith. The most favorable environment for iron solution and concentration is found in a warm humid climate where bacterial growth is uninhibited and leaching of silica tends to take place. After solution and deposition, the iron occurs either as ferrous (FeO) or ferric (Fe_2O_3) oxide. The ferrous oxide (colorless or blue in color) is very unstable and tends to pass easily into the ferric form (orange or yellow). Eventually all the iron in a sediment or soil passes into hydrated iron oxide provided no active-

ly reducing environment is present. The process becomes obscure at this stage. Dehydration of yellow iron oxide into red anhydrous oxide takes place at surface temperatures in many of the warm regions, but cannot be duplicated in the laboratory unless much higher temperatures are used.

Red color may frequently also appear directly in some of the hydroxides (turgite) and then the sediments are red from the beginning. Raymond says that treatment of ferric chloride or nitrate (as produced by bacterial action or even directly by tropical thunderstorms as described by Walther) by an alkaline hydroxide gives origin to a red hydroxide. In this connection, it may be interesting to mention that, according to Robinson (1932, p. 139), the amount of nitric acid brought down by rainfall is in England only 4 pounds per acre per year, whereas in Indo-China it increases tenfold, reaching 30 to 35 kgs. per hectare.

Fortunately even though our knowledge of the genetic chemistry of the red iron oxides is far from satisfactory, we possess definite information as to the natural conditions under which red iron pigments are formed at the present time.

Post-diagenetic red color in sediments initiates a new cycle of red pigment formation due to weathering of outcrops. Iron-bearing minerals are altered and the iron goes into solution and is redeposited either as a ferric or ferrous compound, in the latter case to be oxidized to ferric. This process, which accounts for most of the rusty and buff weathered rock surfaces of the temperate zone and the red exposures of the tropics, has been referred to colloquially among geologists as "running" of the iron ores or "leaching" of the biotite. Some of the German geologists (Wasserstein, Kautsch) have claimed that the red color of the Buntsandstein is due in toto to secondary changes and weathering. On the whole, however, the possibility of great and deep penetration of red color into a sedimentary layer appears to be definitely limited. The Hueches formation of East Texas, red at the surface and green (glauconitic) at depth is a good example of this.

The possibility of diagenetic red color assumes spontaneous dehydration of yellow iron oxide under hypothetical conditions of long time and extreme pressure. If this be true, then the process is highly selective, for red and yellow beds are intimately interlayered in systems as old as the Cambrian (Potsdam sandstone). This process is theoretically possible, but it is difficult to visualize, with the exception of the deep-seated oxidation of some iron carbonate upon introduction of oxygen by fluctuation of the water table or similar processes.

Primary pre-depositional red color is due to the deposition of red detritus originating from the erosion of red soils; primary post-depositional penecontemporaneous red color is due to sub-aerial

weathering of a sediment and is nothing but the formation of a red soil on alluvium. *The color of practically all non-calcareous continental red beds, including those of the Connecticut Triassic, is of primary origin.*

Climatic Significance of Red Soils

At the present time red soils are formed over enormous areas. They cover more than half of Africa and South America, one-fifth or more of Asia, a sizable part of North and Central America, and smaller areas in Europe. Hundreds of papers and pamphlets describing these soils and their climatic environment have been published by the soil and agricultural surveys of the various governments. All this strictly factual and non-debatable information has been summarized in several reputable text and reference books (Blanck, Marbut, Robinson, Twenhofel). Boiled down to the barest fundamentals, the facts are that:

1) 95 per cent or more of red soils are found in warm and humid regions, specifically in regions with a temperature exceeding 55° or 60° F. and a rainfall in excess of 40 inches.

2) 5 per cent or less are found in regions which *at the present time* have a smaller rainfall, or a lower temperature, or both.

This statement can be immediately verified by a simple comparison of the soil distribution map in the third volume of Blanck's treatise with any good rainfall and temperature map of the earth's surface.

A discussion of the subject appears, nevertheless, necessary because some geologists are of the opinion that red soils are proof not of a humid climate, but only of a warm one. As an example, it has been said that red soils in Europe do not occur above the 61° isotherm, and that this Mediterranean region possesses a sub-humid rather than a humid climate with some of its districts bordering on semi-aridity.

The following remarks can be made concerning this opinion:

1) Most of the Mediterranean red soils are terra rossa, a red earth developed on limestone and of entirely different origin and genetic significance from the ordinary red soils formed on crystalline silicate rocks. So far as total areal extent goes, red soils on crystallines outnumber the terra rossa at least 50 to 1.

2) It has not been proved that the Mediterranean red soils (both terra rossa and ordinary red soils) are products of recent weathering. On the contrary, it has been suggested that to a considerable extent they are very old, of Pleistocene or even pre-Pleistocene age, and, to an unknown degree, are the products of climates different from the present one, and probably much more humid. On the island of Capri, the terra rossa (5 meters in thickness)

has yielded skeletons of elephants, hippopotami, etc. (Walther, 1924, p. 391). Incidentally, a similar situation exists in certain of the American deserts of the Southwest where most red soils are really fossil relics of the much more humid climates of the Pluvial Pleistocene.

3) Red soils in pre-glacial time extended over most of Europe. The Red Crag of England, the red ground moraines of the Netherlands and Holstein, the "bloody clays" of Bavaria are, according to Walther, reworked, deeply weathered red soils (1924, p. 391: "die bei der diluvialem Abtragung erhalten gebliebenen Reste Ausgedehnter roter, tiefgrundig zersetzen Gesteinmassen"). Red soils apparently extended as far north as Scandinavia, judging by the red varved clays of the Stockholm district (De Geer, 1932, p. 23). Hence, it seems that to some extent the Mediterranean red soils owe their existence and survival to the fact that they are located in a region which was not glaciated during the Pleistocene.

These remarks show that, due to the extreme complexity of the geologic and climatic records, the Mediterranean red earths can not be used as a valid example for the definition of the climatic significance of red soils. In addition it should be remembered that so far as total areal extent goes, the south European soils are as nothing compared with the gigantic areas of red soils in South America, Africa, Asia, and, to a lesser extent, the United States.

A perfect test case can be made out of Africa. This continent lies almost entirely within the 70° isotherm. Hence all of its surface should be wholly red. The literature contains many descriptions of the Sahara desert and the semi-arid steppes and velds of Africa, in all of which the red color is conspicuous by its absence. But, if we turn to the excellent work of Marbut and Shanz (1923) on the soils of Africa we see that red soils occur only in the very humid parts of the continent. Looking at Marbut's map it is remarkable to see to what an amazing degree the distribution of red soils follows the sinuous line of the 40 inches isohyet. In South America, where red soils cover more than half the continent, Matthei (1931) describes red soils as forming under a rainfall exceeding 1,400 mm. (56 inches). Coming to Asia, it can be seen that in China (Thorp, 1935) podsolized red soils are limited by the 35 to 40 inches isohyet, and true lateritized red soils are forming in regions with a rainfall of 45 inches or more. Similar results come from the Dutch East Indies, with possibly even a heavier precipitation (Mohr, 1933).

Finally, an examination of Marbut's classical atlas of the soils of the United States (1935) will reveal that the red soils(a major unit of the "broad climatic environment group") are decidedly restricted to regions with a rainfall of 40 inches or more, and only very infrequently make forays into the zone where the rainfall fluctuates between 35 and 40 inches (compare with Ward's 1925 rainfall map

of the United States). The lower temperature limit defining the distribution of the red soils in the United States is not 60° F., but 55° F. and possibly even somewhat less than that.

Specifically, the red soils in the United States occur in two major groups: 1) the red soils of the southeastern states, where the rainfall averages 45 inches; and 2) the red soils of the western slope of the Sierra Nevada, where the rainfall also averages between 40 and 50 inches. The rainfall on the slope increases with the altitude and decreases from north to south, but remains high even near the southern extremity. Springville, directly east of Lake Tulare has, according to the official data of the U. S. Weather Bureau, a precipitation of 35 1/2 inches per year. A study of the rainfall map of the California Department of Public Works (1923) shows that in no place on the western slope of the Sierra does the rainfall shrink to less than 25 inches, and that more than four-fifths of the slope receives in excess of 35 inches, and at least three-fourths over 40 inches of rain.

In addition to these two major groups, red soils are found to a very much smaller amount in semi-arid parts of California. These are the San Joaquin series, which have been said to be of local, arid origin and as such are given by Robinson (1932, p. 236, after Shaw, 1928) as one of the only two recent examples of arid red soils on the surface of the globe. However, Marbut made the following statement concerning the San Joaquin series (1935, p. 83):

> "It is not at all certain that the San Joaquin and Madera soils are not the product of development under a former and different climatic environment from that now prevailing in the region."

This brings the necessity of discussing the rest of the 5 per cent of red soils which are found outside of warm and *humid* regions. The San Joaquin series and the terra rossa have both been mentioned already. Other instances of non-humid red soils are some of the red sands of the south Algerian Sahara, of the Arabian desert, some red soils of Persia, and the red sand and soils of Australia. The Algerian occurrences have been shown by Aufrére (1931) to be red Oligocene fluvial sands, the Asiatic occurrences are recognized by Walther (1924, pp. 253 and 286) as the products of another more humid climate, the red dust of Australia is due to the erosion of a fossil lateritic "duricrust" (Woolnough, 1930, and Walther, 1924, p. 286). Walther specifically cautions (p. 253) against interpreting red soils as results of recent arid or semi-arid weathering when they are the product of an older climatic cycle.

It will thus be seen that upon critical examination, this 5 per cent of non-humid red soils disappears entirely and that the ratio of humid to non-humid red soils becomes somewhat like 100 to 1. This is not difficult to understand if the essentials of the formation of a red soil are considered. According to Robinson (1932, pp. 90 and 92) reddish, brownish, or yellowish clays represent considerable leaching:

"These conditions obtain in all humid climates in situations with free drainage. Concurrently with degradation silicic acid may be removed under climatic conditions which favor rapid mineralization of plant residues (i.e., oxidation and bacterial action) and a slightly acid soil reaction ....The red and yellow soils of tropical and subtropical climates probably differ from the brown earths of temperate climates both in the extent to which free Sesquioxides have been liberated and also in their degree of hydration."

On the other hand, gray or brownish-gray clays are formed (p. 90) by weathering under restrictive leaching (arid, semi-arid climate, or impeded drainage). This modern description has reversed Barrell's assumption that the fine-grained red material indicates semi-aridity, whereas the paler clays point to those postulated by Barrell.

Robinson explicitly recognizes this fact (p. 246):

"In humid climates red colours indicate degradative changes affecting the weathering complex under the influence of a lowered base status. This can scarcely be the case in red desert soils and, if the red colours have actually been developed by desert weathering the mechanism still remains to be explained."

Having thus commented upon the apparent impossibility of non-humid red soils, Robinson nevertheless proceeds to give several examples, presumably as the exceptions to the rule. These examples are:

1) The San Joaquin series of California (see the comments of Marbut).
2) The Old Red sandstone (p. 169).
3) The Triassic (pp. 92 and 169).
4) The Karoo of South Africa (p. 257).

It appears that in these last three examples the past should be the key to the present, not considering the fact that these are not red soils but transported sediments of a very debatable origin. As was said before, Robinson quite frankly admits that these so-called "red desert soils" are difficult to account for through processes which are known to be operative at present on the surface of the globe. He accepts their desert origin, however, because geologists say so (!). Quoting Robinson (p. 92):

"Certain tropical desert soils, in spite of the restriction of leaching by arid conditions, may show bright red colours suggesting the liberation of sesquioxides. It seems possible that in such cases the stability of the siliceous clay minerals is affected by the high temperature. The writer has found silica-sesquioxide ratios considerably greater than 2.0 in certain sediments of the Trias, a formation which is considered to have been laid down under desert conditions."

This again indicates the necessity of a revision of much of the work done so far on these pseudo-arid and allegedly semi-arid formations of the past.

In conclusion it seems that, with the exception of a few scattered and isolated patches of red soils of dubious origin, practically all the

red soils are formed at the present time in warm humid climates only, mostly in tropical and sub-tropical regions with a seasonal and heavy rainfall. A good drainage is necessary, but this does not necessarily imply hilly topography. A gently undulating, almost flat savanna with intermittent streams provides an ideal place for the formation of red soils, to depths which may reach 50 feet or more. Flattish interfluves between canyons and even moderately gentle slopes within some mountain ranges also provide red soils.

It has been said before that a certain amount of time is necessary for the development of the red color and that the red soils grade into yellow ones at depth. This is confirmed by the color differences observed by the writer in Mexico between a flat savanna where chemical decay proceeds uninterruptedly and the adjoining forested foothills where erosion is active. As described above, the freshest debris often comes from the denuded canyons. Decomposition, however, takes place on the better protected gentler slopes. In the hills, instead of the monotonous red soils of the savanna, there is among the residual clayey material under dense jungle much red, somewhat less yellow, a little white, and a rather small amount of blue color (Krynine, unpublished observation, 1930). It seems that here indeed can be seen a complete cycle from blue ferrous to red ferric compounds with the former finally spontaneously passing into the latter under our very eyes.

In contrast with the enormous extent of red soils in the humid tropics, no indisputable recent red soils are known to form in desert or semi-arid regions. These facts have been summarized by Twenhofel, who writes (1932, pp. 278 and 290):

> "Red soils are formed on a considerable scale only in warm and moist, usually upland regions with good subsurface drainage" and "It is thought that the materials of the 'Red Beds' originated under moist and warm conditions."

If the present is the key to the past, one thing appears to be certain: that is that widespread primary red color in sediments is prima facie evidence for a warm, humid (preferably tropical or subtropical) climate in the source region from which these sediments came.

This introduces the necessity of differentiating between the conditions prevailing at the source area of a sediment and those present at the place of deposition. Red argillaceous matter arriving from a hot, moist country may come to rest in a desert basin in the company of salt and gypsum beds. Such red beds will be red in spite of their desertic associates, not on account of them. In order to prove what conditions prevailed in the basin where these sediments were depo-

sited it is necessary to resort to additional evidence besides that of red color proper.[13]

Deposition of Red Beds

While there can be no argument whatever as to the humid origin of red soils, the possibility arises that the resulting red detritus may be deposited under other climatic conditions. The prevailing view on the subject is well stated in "Textbook of Geology" (Longwell, Knopf, and Flint, pp. 229 and 228):

"In conclusion, red strata occur chiefly in terrestrial formations, especially in those that accumulated in warm arid or semi-arid regions; but red color in itself is not proof of any one depositional environment.

"However, red soils form where the relief is sufficient to insure free circulation of the oxygenated water of the rainfall; but in the lower, swampy tracts, vegetation is luxuriant, the stagnant waters become depleted of their oxygen, and strongly reducing conditions exist because of the excess carbon. Therefore, even if red sediments are deposited in the swampy tracts of humid regions, the red color tends to disappear and the sediments turn dark. As sediments are generally deposited in the lowest places, it follows that there is small chance of forming red deposits in humid basins. But in the desert and in regions of seasonal rainfall, life is sparse, and the soil becomes dry and its content of humus becomes oxidized during the periods of drought. No reducing conditions obtain here, and if red sediments are washed in from the more humid uplands or slopes they are likely to remain red."

This view is quite sound and it applies with full force to the depressed central portions of humid basins of deposition. The areas covered by these swampy tracts are indeed very great, especially in the larger humid basins such as the Amazon region. However, sedimentation may proceed in a somewhat different way on the flanks of these large humid basins, or in some deltas, or on piedmont plains. There, sediments are deposited not in a topographic depression, but on a drained slope (floodplains). As a result, although the floor of the major unit of deposition (delta, piedmont, etc.) subsides, its sur-

[13] The following classification of "Red Beds" was worked out by P. D. Krynine in 1942 and has been published in the Trans of the New York Academy of Sciences, Vol. 2, p.p. 60-68, January 1949. An abbreviated discussion is to be found in the A.A.P.G. syllabus mentioned under arkoses:

1. Detrital red beds (generally continental): Sespe of California; Triassic of Connecticut and other eastern U. S. basins; Triassic and Permian of West Texas; Devonian Catskill of Appalachian region; European "Old Red" and "New Red." Most of these are of tropical humid origin; a few are of semi-arid or arid origin.
2. Early post-depositional red beds: Irawady delta near Rangoon.
3. Authigenic and chemical red beds: generally marine of the Clinton iron ore type.
4. Diagenetic red beds (intrastratal or post-emergent oxidation of iron carbonates or glauconite): some Permian types and the Tertiary Hueches formation of East Texas.
5. Second cycle, reworked, detrital red beds (eolian, glacial and so on): Navajo formation of the western U. S.; "bloody clays" of Scandinavia; "Pink sand" and glacial clay of Connecticut.

face at all times remains well drained. Hence, swamps—which are a major feature of the central parts of the larger humid basins—are a distinctly subordinate feature of piedmont deposits. On the contrary, piedmont alluvial deposits are usually made up of a series of coalescing, dissected and well-drained, alluvial fans and floodplains.

It appears, then, that it is necessary to differentiate between two distinct realms of continental sedimentation: deposition in a topographically depressed basin and deposition on a drained slope. This concept of a non-reducing environment on a slope of deposition was set forth by Barrell in his discussion of the Mauch Chunk shales (1907, p. 468):

> "The surface of the Mauch Chunk delta....possessed a fair grade to the westward, sufficient to prevent the development of broad swamp areas, since in those regions decolorized shales are practically absent. The grade which this indicates varies with the climate."

The downhill slope necessary to maintain dissection and a good drainage can be very low, especially if the rainfall is heavy and seasonal. It is only from one-half to three-quarters of a foot per mile in the Tabasco piedmont. Barrell postulates a slope of 2 feet per mile in the Mauch Chunk delta.

What is the fate of red sediments deposited upon such a piedmont? If the climate is arid or semi-arid, they usually stay red (Great Valley of California). If the climate is uniformly humid, their fate will be diverse. Possibly some of them will be reduced, but there is no conclusive proof that this is always the case. Twenhofel says (1932, p. 281):

> "The redness probably would be retained if the climatic conditions were such as to permit plant growth not beyond the disposition ability of the bacteria of the region."

Finally, if the climate is seasonally humid (savanna type), not only does the sediment stay red, but it even becomes redder, for this is the ideal environment for super-oxidation regardless of vegetation. The fluctuating water table brings a large amount of oxygen to the upper layers of the sediment before its final burial. A dense jungle may grow along the water bodies of such a savanna, but the soil under it is red, sometimes to a depth of 50 feet. The vegetation not only does not reduce the red soil, but is itself entirely destroyed by oxidation and bacterial action. These phenomena have been observed in deep pits dug on the Tabasco savanna. Thick red soils under dense tropical forests have also been described by Behrmann (1915) and Sapper (1935). It can be said in conclusion that *reduction in the presence of an excess of free oxygen is impossible* regardless of the absolute amount of organic matter present.

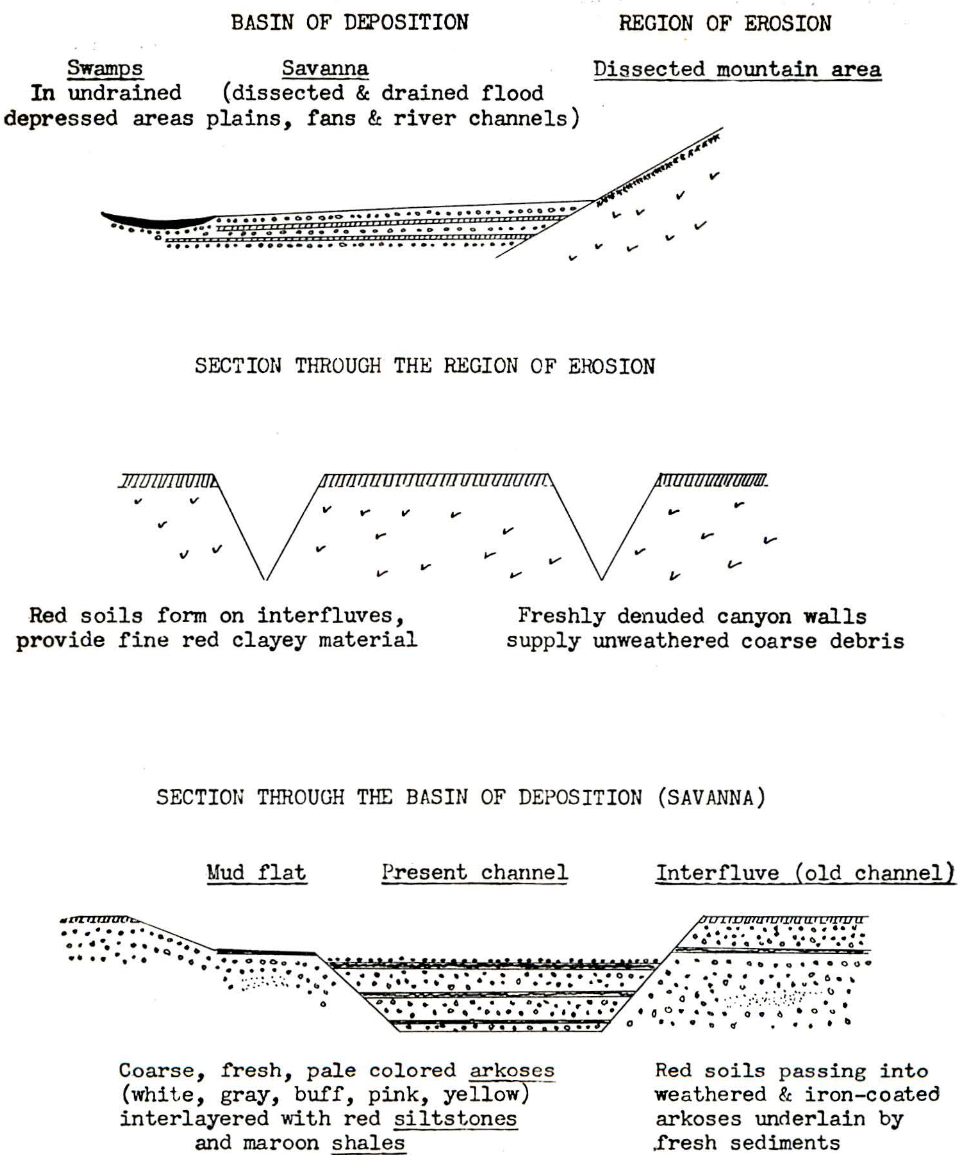

Figure 35. Sedimentation on a recent tropical piedmont showing a double locus of chemical and physical weathering in area of erosion and a double locus of sedimentation in region of deposition. Illustrates formation of arkoses and red beds under typical continental conditions.

The Tropical Piedmont—Typical Site of Deposition for Non-arid Red Beds

Sedimentation on a tropical piedmont, as observed on the Tabasco savanna, proceeds along the following lines. During the rainy season the stronger floods bring in the coarser fresh material from the denuded canyon walls of the forested mountains. Several floods per year are of the type of super-floods mentioned by Von Engeln (1936). They produce marked major erosion and sedimentation, directly observable (Krynine, 1935a, p. 361). Weaker floods transport, sort, and deposit the red mud derived from the red soils washed down the slopes from the mountain interfluves. These sediments form alternating beds of coarser, pale-colored (white, gray, yellowish, or greenish) arkosic sands and finer-grained reddish or maroon siltstones and shales (Figure 35 and Plate XXVIII-B). Partially decomposed and iron-coated mineral grains and iron concretions from the subsoil may be incorporated in either the finer or coarser beds. As erosion is localized in the canyons, most of the detritus is coarse-grained and fresh. In the meantime, depending upon the rapidity of the sedimentation process and the frequency with which the river channels shift their courses, weathering of the sediments proceeds on the savanna interfluves (i.e., on the older channels). If deposition slows down, then chemical decay becomes very noticeable. Red soils are formed and the top layers of the underlying coarser sediments become coated with ferric oxide and change their color from pale tints to red. The deeper underlying arkoses remain fresh. If sedimentation is very rapid, then this post-depositional weathering is not very important.

During the dry season mud cracks and other desiccation marks develop on the mud flats left by the shrinking water bodies (Krynine, 1935a, p. 362). Sandstorms filling these cracks with finer material have been not infrequently observed. Even the soils on the interfluves often become deeply cracked (Bennett and Allison, 1928, pp. 89, 212, 218), and crystals of soluble salts (gypsum, halite, etc.) may form (Bennett, etc., pp. 184 and 218).

Finally, if the drainage is disturbed (damming, tilting [as on the lower coastal plain of Tabasco], or loss of relief of the mountain region, etc.), meandering rivers and swamps make their appearance and reduction of the *upper* layers only of the sediments may take place.

As a whole, the sediments of a savann a show color banding and variegation (Krynine, 1935a, p. 359), and also a variation in the freshness of the sediments from the freshest feldspars through weathered, iron-coated or somewhat altered grains and into deeply weathered maroon clays and shales. Such an alternation of varicolored and differentially weathered (i.e., partly pre- and partly post-depositional) material can hardly be duplicated under any other com-

bination of climatic and topographic conditions. Such an alternation of variegated and differentially weathered beds is typical of the Triassic sediments of Connecticut, of the Sespe formation of California, of the Siwalik beds of India, of the Juniata formation of Pennsylvania, and many other continental red beds of the past.

Interpretation of the Triassic Sediments

Fanglomerates

Fanglomerates have been described by Lawson (1913) as the coarse, angular material formed at the apex of alluvial fans under conditions of "bold relief and aridity." They represent an interfingering combination of cliff talus, mudflow material, and ordinary water-laid deposits, but are definitely alluvial in origin, differing in that respect from screes and other gravity deposits.

Lawson originally defined fanglomerates as coarse continental deposits depending upon "bold relief and aridity." Consolidated fanglomerates were described as typical of a local base level of erosion in an arid climate. These definitions are based on environment rather than on process and for this reason cannot be accepted as final. An analysis of the factors involved in the formation of a fanglomerate (or to a minor extent in the formation of any alluvial fan) shows that the real controlling elements are:

1) A localizing factor consisting of an extremely sharp break in slope (Lawson's bold relief and local base level), providing for the instantaneous deposition of most of the jumble of very coarse and ill-assorted material debouching into the flat from the short and very steep valleys of the region of erosion. An ideal localizing factor is a fault scarp, especially an active one which is being constantly rejuvenated.

2) The presence of intermittent streams providing the brief and catastrophic floods which are admittedly well suited to transport and deposit coarse, angular, unsorted detritus.

It is obvious that an adequate localizing factor, such as an active fault scarp, can be located anywhere on the surface of the globe. The question is, is the kind of intermittent stream necessary for the formation of fanglomerates an exclusive feature of arid regions or not?

Leuchs (1933) strongly objects to this view and points out that the sudden thawing of snows in a glaciated, oversteepened mountain valley will accomplish exactly the same kind of work and result in the deposition of precisely the same kind of coarse, angular debris. The presence of fanglomerates in the Berkeley hills suggests that the violent seasonal precipitation of a semi-arid region is also adequate for the purpose. Finally, as shown by Sapper, rainfall in an ultrahumid tropical region with its short catastrophic downpours is able

to account just as well for the formation of fanglomerates on a large scale if a suitable topography is present. Specifically, extremely angular material is provided by the slumping of the steep, rocky canyon walls. No large-scale recent fanglomerates have been described as yet from the humid tropics, but considering that to a large extent this region geologically is still a terra incognita, this is not a powerful argument. Minor fanglomeratic deposits have been observed by Krynine in Chiapas in the shape of small incipient alluvial fans at the confluence of intermittent mountain torrents or where these streams debouch into valley flats (Plate XXVII-B). These little fans contain extremely angular boulders up to 5 feet in diameter embedded in a matrix of smaller fragments of varying size and angularity mixed together with fine sandy material (Krynine, 1935). The possibility of mud flows in the tropics (Krynine, 1935a, p. 362, and Sapper, 1935) also must not be ignored in this connection. It is indeed permissible to speculate as to the size to which the small Chiapas fans would grow if an active structural feature, the size of the Connecticut Great Fault, were present in the hilly parts of the humid tropics. Waibel (1934) has also reported fanglomerates from the central part of the same state of Chiapas.

However, if no large-scale fanglomerates of recent age have as yet been reported from the tropics, at least one fossil occurrence can be cited where there is good reason to suspect the climate was just as humid as it is today. This is the so-called "Big Conglomerate" of presumably Lower Oligocene age from northern Chiapas, Mexico. From the fossil record (lignite and tropical fauna both above and below the conglomerate and some lignite within the conglomerate itself) and the broader geographical climatic relationships which apparently were not different from the present day, it appears that the climate at that time was probably similar to that of the present —i.e., humid tropical. A description of the Big Conglomerate (condensed from an unpublished report prepared in 1930 by P. D. Krynine for the Standard Oil Company of California) follows:

"The Big Conglomerate, exceedingly hard and massive, is composed mostly of limestone boulders (pink, black and gray) and to a lesser extent of granitic and schist pebbles. These pebbles show but little rounding, some being extremely angular, and they range in size from 1 inch to 2½ feet, averaging well over 2-3 inches in diameter. A large percentage of big ones is to be found among them. Enormous isolated sandstone boulders up to 20 feet in diameter (from the underlying Eocene?) have been seen several times. The conglomerate is cemented with calcareous cement at most places, but in some instances the cement is siliceous or ferruginous. In a quite subordinate position are a few layers of banded sandstones and shales. The Big Conglomerate extends for 30 km. in an E-W direction. It reaches a maximum thickness of 2,000 feet in the middle, thinning to a few hundred feet on both flanks."

In conclusion, it appears that fanglomerate cannot be restricted to arid or semi-arid regions, but should be considered as possible under any strongly marked seasonal system of precipitation, provided an adequate break in slope is furnished by the topography.

Fanglomerates are one of the most prominent features of the Newark, extending all along the Great Fault, almost from the shore of Long Island Sound past Northfield to the New Hampshire line. As described in the previous chapters, they form rather small fans, the really angular material not extending more than 2,000 feet away from the fault. The angular, brecciated fragments show a rude bedding and at many places are interlayered with perfectly banded arkoses (Plate XXV-A, East Portland), red laminated shales (North Guilford, Northfield, and other places), and extremely fine, laminated, dark-colored siltstones (Plate XXIV-A, Lake Quonnipaug reservoir). Lignite is present in these arkoses within 250 feet of the fault (northwest of Chestnut Mountain). Isolated wood fragments and organic material in the arkoses and siltstones interbedded with the fanglomerates have been observed in several instances within 100 feet of the fault. Large tabular boulders, roughly oriented in a fine matrix and possibly suggesting mudflows, are found one-half mile west of the fault on the road from Lake Quonnipaug to the North Guilford church. Similar tabulate "mudflow deposits" occur at Mount Toby and have been described by Bain (1932).

Most of the material appears to be extremely fresh, but a careful examination of the face of one of the better and fresher outcrops in a recent roadcut will show that some of the fragments are weathered and possess a red iron coating. Exactly the same phenomenon can be seen under the microscope. In a thin section of fanglomerate from Lake Quonnipaug the fragments of Bolton schist show differential weathering: one is perfectly fresh, whereas its neighbor in the same section is weathered, being coated with ferric oxide and all its cracks filled with it (Plate XIX-B).

All these phenomena associated with the fanglomerates are not restricted to one horizon, but occur at all levels in fanglomerates of both the Meriden and Portland formations. Summing up, it can be said that the Triassic fanglomerates of Connecticut, besides being typical fanglomerates, possess in addition the following features: 1) They are intimately associated with plant remains and extremely fine, dark sediments containing organic material. 2) Their coarser local constituents show differential red weathering, and in places they are conformably interlayered with reddish shales, which presumably debouched from the same valleys as the coarse angular debris.

These Connecticut Valley fanglomerates, inasmuch as they consist to some extent of local red detritus, must have originated in a climate adequate for the occurrence of red soils. The high humidity postulated by this hypothesis also explains the occurrence of lignite and plant remains within the fanglomerates, pointing to a forest cover on the very short slopes from which the debris originated.

Arkoses and Sandstones; Significance of Differential Mineral Weathering

Medium-grained clastics form almost 65 per cent of the section (76 per cent of the New Haven arkose, 38 per cent of the Meriden formation, 57 per cent of the Portland arkose).

The most remarkable feature of these arkoses and sandstones is their angularity of grain and their high content of unweathered feldspar, to which can be added, for the truer arkoses and the semi-graywackes, an extremely poor sizing. These are all features of continental deposition and unmistakably suggest violent erosion.

From a study of over 125 thin sections, it appears that as a whole, the feldspars are very fresh. Some of the so-called "weathering" may be either hydrothermal sericitization (only locally developed near igneous bodies) or replacement by carbonates, generally calcite (also a somewhat local process, in the general vicinity of fault planes). Calcitization may result in the destruction of feldspars by piecemeal attack and replacement, but the unreplaced portion of a feldspar grain is quite fresh inside and does not show any internal changes, i.e., remains unaltered and "unweathered."

When replacement by carbonates is not present and when the specimen is not unduly affected by recent weathering, it is possible to notice distinct differences in the degree of alteration in the *same* variety of feldspar (microcline vs. microcline or plagioclase vs. plagioclase) which, as shown in the chapter on Petrography, are of primary origin. This can be seen well in Plate XXIX.

This mixture of very fresh and weathered material becomes much more conspicuous in the finer-grained brick-red feldspathic sandstones of the Redstone type. In the Redstone, perfectly fresh grains of feldspar and biotite are often embedded in a red gibbsite-bearing clayey matrix which may form as much as 45 per cent of the rock. In other words, the primary constituents of the arkoses range from perfectly fresh feldspars and ferromagnesian minerals through somewhat altered material and into lateritic clays, the final product of a process of extreme chemical decay.

This mixture, which was found to be present in every Newark specimen examined, implies a double locus of erosion in the source area. One of these loci provided the fresh minerals, the other locus the deeply altered material. Since it is impossible to get two different climates to operate at the same moment at any one place, it follows that the same climate was operative in both loci, but that in one of these loci the chemical action was sufficiently prolonged to produce a lateritic clay, whereas in the other locus, this action was interrupted by violent erosion and did not have time to become effective. The exact structural and topographic mechanism necessary for this is shown in Figures 34, 37, and 38.

On the basis of these facts, and knowing also that an extremely steep topography was provided for erosion by the scarp of the Great Fault, the following interpretation of the arkoses becomes possible.

The fresh feldspars and the very decayed red gibbsite-bearing clayey matrix indicate in the source area the presence of both extreme erosion and very potent chemical action. The latter requires a high temperature and a heavy rainfall. The steep relief necessary to provide an erosion rate sufficient to account for the formation of arkoses is present, provided the rainfall occurs mostly as cloudbursts. Such an uneven distribution of heavy rainfall is a feature of tropical humid climates, especially of the seasonal savanna type. This is the climate which can be safely inferred for the source area of the arkose. The preservation of arkose deposits under exactly the same humid tropical conditions has been shown to be possible if deposition is rapid enough (Krynine, 1935a, Sapper, 1935). As shown in the preceding section, during Triassic time both source area and basin of deposition of the Connecticut Valley sediments formed one single climatic province. More complete proof of this will be offered later.

Red Beds

A small amount of the red color of the Connecticut Triassic is due to recent weathering (as at Pine Rock). Usually, however, the weathering of Triassic non-red beds yields yellow limonitic material (as with the white arkoses of the upper Meriden formation).

Not counting recent weathering (i.e., on the basis of fresh and relatively unweathered outcrops) more than 52 per cent of the section is found to be definitely red (i.e., not mottled in shades of pink and gray, etc.); 45 per cent of the New Haven arkose, 50 per cent of the Meriden formation, and 63 per cent of the Portland formation consist of red beds. On a lithologic basis, 31 per cent of the arkoses, practically all of the siltstones, and 70 per cent of the shales are red. Within the coarser sediments (arkoses and conglomerates), possibly in as many as half of the occurrences the red color is due to fresh pink feldspar or to feldspar reddened by incipient decay and infiltration by hematite. The other half, together with all the red siltstones and red shales, are colored by disseminated red iron pigment. Not less than 40 per cent of the section is red because of primary or early post-depositional coloration with ferric oxide. That this color is prediagenetic can be conclusively proved at Reed Gap quarry where a red arkose is bleached to a white color by thermal action immediately below the lower contact of the middle lava flow (see the section on stratigraphy and petrography of Reed Gap quarry, giving the microscopic description of the passing of hematite in the lower arkose layers into magnetite in the upper; also see microphotographs on Plate XVII). Inasmuch as the lava sheets flowed over Connecticut during the very process of Triassic sedimentation, it is certain that red color

existed already in the topmost unburied sediments as the result of primary depositional or post-depositional sub-aerial action before the extrusion of the lava.

The primary, pre-depositional character of some of the red detritus has already been discussed in the section on fanglomerates. Most of the color of the red clays which form the finer red shales and most of the matrix of the siltstones is apparently of primary origin. A very small part of these red clays, which also form the fine laminated red shales, may have been imported into the valley from a great distance by some longitudinal master streams, but most of them are definitely of local derivation as shown from their association with fanglomerates and especially from their mineral composition, as described in detail in the correlation between the Lamentation and Redstone facies (Tables 8, 9, 10); some of the ferric-oxide films coating single sand grains in the coarser clastics appear to be also of primary origin, judged by their relation to the cementing medium. The color of the differentially weathered red pebbles of the fanglomerates is primary. In other instances, however, these iron films seem to be post-depositional, being of a later origin than the clastic constituents and some of the cement (no coating at point of direct contact between some of the grains). This seems to be the case in some of the arkoses from Portland, where, in addition, small, round, complex concretions consisting mostly of ferric oxide apparently occur as primary depositional or detrital constituents of the rock on a par with sand grains. Similar concretions occur also at Shepard Avenue (loc. 17). These round concretions appear to be closely similar to the perdigon (buck shot) of the soils of Cuba described by Bennett and Allison (1928, pp. 77-80).

The following conclusions can be arrived at from these observations:

1) Primary red detritus has been derived to a considerable extent from *local* sources immediately east of the Great Fault, within a few miles, or possibly within a few hundred feet, of the basin of deposition. There is no evidence that the fault scarp formed a lofty mountain range towering thousands of feet over the valley. On the contrary, its absolute relief seems to have been very moderate. Hence it is impossible to postulate two different climatic provinces, one for the very moderately elevated (and very narrow) scarp, another for the lowlands less than 5 miles (or possibly in part less than 500 feet) away. If red soils could form on the interfluves of the region of erosion, then the climate of both the scarp region and of the valley immediately west of it must have been warm and humid.

2) In addition to the climatic evidence provided by primary red detritus of local derivation, it seems that some of the red color of the Triassic is due to early post-depositional sub-aerial weathering of the deposited sediments. This is direct evidence of a warm and humid climate in the valley itself.

On the basis of all this, it appears that the climate of the Newark epoch in the Connecticut Valley must have been warm (and probably hot) and decidedly humid (rainfall in excess of 40 inches). While providing a good clue to the absolute rainfall (high), the red color does not furnish satisfactory evidence as to the character of its distribution (uniform or seasonal). This problem must be solved on the basis of other climatic evidence, such as the presence of highly aluminous clays (gibbsite).

Dark Shales and Limestones

The term black shales introduced by Davis to describe the dark fossiliferous beds of the Meriden formation includes not only true black shales, but also bluish-gray and dark-gray shales, limestones, and dolomites, grayish, bluish, and greenish siltstones, white, gray, and black feldspathic sandstones, all of which are interbedded to some extent with red arkoses, siltstones, and shales, and in the vicinity of the Great Fault even with conglomerates and fanglomerates. The bedding, however, is rather thin, and the finer, dark-colored sediments are a feature of almost every outcrop and permit an immediate identification of the series. Deposits of this type are universally present at least at two major horizons in the Meriden formation: immediately above the lower lava sheet and in the middle of the upper division of the Meriden beds. These two major horizons form a continuous cover over the whole Triassic basin of Connecticut, including the Pomperaug valley, and their outcrops can be found without a single exception at the places where stratigraphy and structure require their presence. This complete continuity indicates that the Connecticut basin of deposition was entirely blanketed at least twice by dark sediments.

The lower horizon consists to a very large extent of lacustrine deposits: perfectly banded and laminated dark and red shales, limestones, and very fine siltstones, partly organic, partly calcareous, partly (to a very minor degree) dolomitic. These lacustrine deposits extend from Northford to New Britain and are also present in the Pomperaug area. They gradually pass at top and bottom into less perfectly banded and coarser variegated siltstones and arkoses.

The upper dark shale horizon does not have such a marked lacustrine character, but consists of a bewildering complex juxtaposition of beds from limestones to arkoses, very lenticular in character, but homogeneous in their heterogeneity in the numerous exposures from Branford to the north of Massachusetts. Mud cracks in some of the black shales indicate sub-aerial exposure and suggest that the bodies of water, although numerous, were discontinuous and shallow. The general scarcity or even absence of definite lacustrine or fluvial features in these beds suggests that they are probably of swamp or marsh origin. An enormous, poorly drained marshy lowland composed of swamps, minor lakes, sluggish meandering streams, and

patches of dry ground seems to have covered the Triassic basin during a large part of Meriden time. As shown in the chapter on Structure, this was due to a disturbance of the drainage, probably caused by warping. A luxuriant vegetation flourished on the shores of these marshes, and myriads of fishes thrived in the clearer of the water bodies, most of which were definitely shallow and fluctuating in their extent, judging by the evidence of mud cracks (although mud cracks are absent in the fish-bearing parts of the shales).

After the eruption of the lower lava flow, the damming action was sudden and complete. This resulted in the complete closing of the drainage outlet and the development of large lakes in which fine-grained sediments including limestones were deposited. The perfect banding of the lacustrine shales south of New Britain, almost varve-like in appearance, points to recurrent processes of cyclic sedimentation due to the change of wet and dry seasons. No desiccation marks have been found as yet in the typical lacustrine shales. Indisputable desiccation marks have not been positively proved to exist in the limestones, either. Contorting of limestone layers is frequent, but it seems to be due to the disturbing action of bottom currents. The perfect rounding of many minerals, even including micas, in the lacustrine beds (an unheard of feature anywhere else in the Triassic sediments) and the microscopic character of some ultraminute cut-and-fill stratification in the dolomitized siltstones prove the existence of very gentle bottom currents. Finally, some of the features in the limestones which appear to have been possibly mud cracks do not resemble authentic polygonal mud cracks, but rather the shapeless cracks obtained by Jungst (1934) in his experiments on synaeresis, a process typical of calcareous muds (sub-aqueous dehydration of colloids).[14]

It has been said that lacustrine sediments prove an arid climate. As a matter of fact, a lake proves: 1) the presence of a basin; and 2) an abundance of water to fill it, the water in most cases being supplied by rainfall. The lacustrine deposits of the lower Meriden formation show banding, indicating recurrent seasons; the limestones are very impure, and contain much sand, pointing to active erosion; there is no salt or gypsum indicating complete desiccation; even mud cracks are absent or at least of a very debatable nature. The lake beds finally pass into calcareous shales, silts, dark arkoses, and other sediments more typical of a swamp than a playa deposit.

The swamp beds of the upper Meriden formation are remarkable for their thickness (up to 400 feet), enormous extent, and continuous character. They cover close to 2,000 square miles. At the

[14] Similar poorly defined mud cracks, some standing below water, were seen by the writer in a calcareous mud while inspecting a water softening plant at Lansing, Michigan, in 1943. Lansing is located in a humid forest climate (subuniform rainfall of 31 inches with an annual mean temperature of 46.8°F.).

present time such large continuous swamps are not easily found outside of definitely humid regions.

A basin-like depression on the surface of a savanna results in the development of such marshes. This can be observed in Tabasco at the junction of the well drained red savanna and the lagoons of the coastal plain. Structural tilting there has resulted in the formation of a swampy trough between lagoons and upland, 10 miles wide and consisting of black-water marshes, small lakes, patches of dry ground, meandering rivers, etc., all of which is covered with a dense vegetation. Similar conditions exist in some coastal districts of equatorial West Africa (Sapper, 1935).

In conclusion, it seems that the formation of a series of continuous swamps covering 2,000 square miles of territory and depositing 400 feet of sediment can hardly be possible, so far as our knowledge of the present goes, outside of a humid climate.

Climatic Significance of Desiccation Marks

Desiccation marks have been well described in the literature, and the following brief review based upon Twenhofel (1932), Grabau (1924), and personal observation, is intended only to bring out their climatic significance. Desiccation marks can be divided into two major groups:

1) Those formed through the breaking of a clay upon drying (mud cracks). To be preserved, they have to be filled with some foreign material before the clay flows together again upon wetting and closes them. Filling with eolian sand before the next submersion is admittedly the easiest way to accomplish this, but this is also quite possible by ultra-rapid sand or silt deposition, immediately after flooding, and before the clay resumes its plasticity. In addition, it has been shown by Jungst (1934) that as the result of synaeresis, spontaneous dehydration of clays may proceed under water, especially if the clay is calcareous.

2) Those formed through the filling with extraneous material of an impression made in the clay by a foreign body (footprints, rill-marks, rain pits). The accepted idea of this process is that a wet plastic mud surface receives upon sub-aerial exposure an impression, then it hardens, and the impression is filled with eolian material which preserves it when the clay is again submerged. However, rapid filling by silt upon submersion, again, will be just as effective. Work by Krynine (1935b) has also shown that if the clay is sufficiently tenacious, a naked, unprotected impression (footprint) can withstand as many as *seventeen* different successive submersions caused by 5.75 inches of rainfall without becoming much blurred. This work (based upon the observation of natural phenomena and not upon less conclusive artificial experiments under laboratory conditions) indicates the necessity of caution when interpreting desiccation marks:

a dozen floods may have passed unrecorded upon them before the overlying sediments finally cast their protective cover.

While these observations on submerged footprints were in progress, Krynine also noted that the same clay, in layers up to 1 cm. thick, would dry up and crack in less than eighteen hours (including approximately six hours of bright sunshine) after a rain. These clay layers were derived from Triassic shales nearby, and were underlain by finely crushed trap rock from a quarry. These conditions closely approximate those which prevailed during Triassic deposition, when relatively thin shale layers were deposited over coarser arkose beds. It is probable, however, that thicker layers of clay may take a longer time to dry and crack. Several days, weeks, or even months of sub-aerial exposure (depending upon the nature of the clay) may be required to produce deep cracks (20 to 50 cm.). Shallow mud cracks, on the other hand, are formed easily and very quickly.

It appears then that, even if Jungst's work on synaeresis is disregarded, desiccation marks cannot be considered a conclusive proof for anything more than a brief period of sub-aerial exposure which may have been not longer than twenty-four hours. It is totally unpermissible to claim that desiccation marks are by themselves a proof of semi-aridity. On the contrary, desiccation marks of all kinds can form with extreme ease in humid climates. Such desiccation marks have been observed in Connecticut (uniform precipitation of 46 inches per year) and on the savanna of Tabasco (seasonal rainfall exceeding 85 inches per year). Bennett and Allison mention the ubiquitous deep cracking of the clays of Cuba during the dry season of a savanna climate, with a precipitation of 50 to 70 inches. The preservation of these features is entirely possible. Raindrop impressions can be seen in the lower layers of the laminated Recent clay described from Pine Rock, Connecticut (Krynine, 1935b). As such, they are already a part of the fossil record. Sandstorms which rage over the barren, dry channels and mudflats of the Tabasco rivers, during the rainless season, fill the mud cracks with eolian material. Extremely rapid deposition during the next flood also greatly favors the preservation of these features.

A conservative qualitative interpretation of desiccation marks cannot go beyond the assumption that they indicate a sub-aerial exposure between two submersions, the length of the exposure possibly being extremely short. It is here that the quantitative element becomes of importance. If desiccation marks begin to be abundant, this reasonably suggests an increase in the frequency of periods of sub-aerial exposure, until finally at a certain point, the existence of definite periods of drought or even of a definite dry season can be safely assumed. Unfortunately, no exact definition can be given for the term "abundant," but if mud cracks, etc., are easily observed in a given formation and are not isolated occurrences, but a common feature which does not require any special search to be seen, then the

word abundant can be applied. Further information as to the length of the period of sub-aerial exposure may be derived from the depth of the mud cracks. Again such interpretation must consider not only the character of the drying up period but also the character (tenacity) of the clay.

It must be remembered though, that a long, dry season and semi-aridity are two very different things. At Bombay not a drop of rain falls for almost nine months, but during the remnant of the year there is 71 inches of rainfall.

Mud cracks, rain pits, and fossil tracks are very common in the Connecticut Triassic. These desiccation marks usually occur in the finer shales and shaly siltstones, but mud cracks and footprints are also present in the coarser arkoses, apparently on account of the abundance of clayey matrix and especially thin clayey layers along bedding planes. Mud cracks have also been observed in the dark shales of the upper Meriden swamp beds, but have not been positively proved to occur in the lacustrine sediments of the lower Meriden formation. As a whole, mud cracks are shallow (1.0 mm. to 1.0 cm.) and only exceptionally exceed 1.0 cm. in depth.

Footprints are treated in detail in the section on Triassic fauna. It may be said, in the meantime, that while many of the footprints are of sub-aerial origin, others (especially those in the coarser sediments) appear to have been formed under water. Two points can be advanced in support of this view: 1) blurred borders, due to the flowage of mud. This, however, might mean thin, wet mud, not necessarily a cover of water. 2) Some of the prints are in very coarse, dark gray arkose which, presumably, would dry and crumble very rapidly upon sub-aerial exposure and thus: a) fail entirely to receive an impression, or b) destroy it if it was recorded while the surface was still moist. Such sub-aqueous prints, recorded under the sluggish waters of the Meriden swamps, would have an excellent chance of preservation, being gradually and slowly filled up with silt and fine sand before the coming of the next violent flood. Such sub-aqueous impressions have been duplicated experimentally to the satisfaction of the writer.

It is believed that the abundant desiccation marks of the Triassic of Connecticut attest to the existence of a well-defined dry season and the presence of a seasonal type of rainfall. Any further assumptions as to the amount of rainfall cannot be made on the basis of the desiccation marks.

Climatic Significance of Soluble Salts

Large deposits of salt and gypsum produced by the complete evaporation of extensive water bodies are a conspicuous feature of desert regions. Glauberite, halite, gypsum, and other soluble salts are forming at the present time in Death Valley and similar places

either as playa deposits or as the product of desiccation of more substantial lakes. All these phenomena can be easily observed and have been profusely described. It is understandable that the presence of these salts has been generally associated with the extreme evaporation characteristic of arid regions. Such a sweeping generalization can be subjected to criticism on the familiar ground that the formation of soluble salts is the product of a process and not of an environment. An arid environment happens to be extremely favorable for the large-scale development of such processes, but its operation is possible—and it has been repeatedly observed and described—under several other entirely different climatic conditions.

The essentials of the process are:

1) Concentration of a solution in a closed basin or at least in a place with a very deficient drainage. On a small scale, and if dealing with a tough, fairly impervious clay surface, depressions 12 inches deep are sufficient to form adequate basins (Bennett and Allison, 1928, pp. 37 and 185) and to provide for a complete stoppage of circulation and an excessive concentration of salts near the surface.

2) Precipitation of the salt due to final supersaturation of the brine, this being achieved best by a high evaporation rate.

In addition to arid and semi-arid areas, such processes of concentration and precipitation of soluble salts have been observed in many humid regions. Robinson (1932, p. 259, after B. Aarnio) mentions the presence of saline soils in Finland. Bennett and Allison, in their monograph on the soils of Cuba, have exhaustively studied the obnoxious concentration of salt near the surface of the ground, a serious problem for the sugar cane industry. The rainfall of Cuba averages between 50 and 55 inches, seasonally distributed with a short but marked dry season. Bennett and Allison summarize the salt-forming process thus (p. 309):

"The low-lying soils subject to long periods of saturation or excessively moist conditions, have not been severely leached because percolation has been retarded; and the material but slightly oxidized because of poor aeration. On the other hand, these soils have accumulated excessive amounts of water-soluble salts, because of their inadequate drainage. In other words, some of the flat, impervious clays have gained rather than lost soluble constituents. This has not been the result of climate, but rather the result of accident of position."

Bennett and Allison give literally dozens of instances of formation of salt and gypsum. A few examples will suffice. On pages 37 and 38, describing the Alto Cedro clay in a region with a rainfall of 42 inches, mention is made that:

"In the lower situation, notably along the drainage ways salt, chiefly sodium chloride is present from the top down in sufficient quantities to form crystals on the dry surface."

Describing the Jucaro clay (p. 39):

> "Sodium chloride . . . frequently present in the subsoil of the higher lying areas and through the entire section of the lower area . . . to give rise to a fluffy structure at the surface (when nearly dry)."

And on page 294:

> "In the Province of Oriente . . . soil in open ditches . . . contained . . . 1% of salt . . . surface incrustations were observed on ditch banks."

It must be noted that much of that salt concentration in Cuba occurs on clays of alluvial origin, or, in the parlance of sedimentology, on unburied subaerially exposed sediments. Such a term fits also the definition of mudflats and playa deposits, in arid regions or otherwise. Some Cuban clayey areas have a soil depth of only a few inches, and some have none at all.

Passing to the presence of gypsum, and again quoting Bennett and Allison, we see on page 37: "broad, thin, leathery sheets of gypsum in fissures"; and on page 39: "amber-colored crystals of gypsum are locally present." An occurrence of gypsum is mentioned in the Bayamo clay of the Trinidad district (pp. 151-152), a region with a rainfall of 52 inches. This example, which is described as occurring in an abandoned channelway of the Manati River in a heavy, sticky recent alluvial clay which cracks during the dry season, can hardly be considered to be in a soil at all, but rather in a real, unaltered, sediment.

On page 219 is shown a large photograph of a "Hardwood virgin forest" growing on the Alto Cedro clay in eastern Cuba in a region with a rainfall of 44 inches. The picture leaves nothing to be desired in the way of a dense, tropical jungle with ferns, enormous trees, vines, creepers, luxuriant and impassable vegetation, etc. A description of the clay on the opposite page (p. 218) shows that it "contains gypsum crystals in many places"; also that:

> "Gypsum crystals are of common occurrence in the lower subsoil. In one deep exposure extensive sheets of leathery gypsum were found in intersecting fissures of the dense clay."

and finally:

> "In some places salt is present in excessive amounts, especially in depressions . . . here salt has accumulated by seepage . . . forming a leathery film or crust."

In conclusion, it appears that Bennett and Allison have satisfactorily demonstrated that:

1) Halite crystals do form on the surface of the ground in regions with a rainfall of at least 44 inches, even in areas which may be heavily forested.

2) Gypsum crystals also occur under similar conditions and even under a rainfall of 52 inches.

3) Salt and especially gypsum form abundantly in the upper layers below the surface, both in soils and in ordinary alluvial clays, subaerially exposed.

The dry season during which these phenomena develop is relatively short (p. 310):

"During the dry season there are often periods when not a drop of rain falls for two or three months."

The mean annual temperature, however, is high: 75° to 79° F., and also uniform: 70° to 75° F. in January, 79° to 83° F. in July.

Bennett and Allison describe the recent formation of relatively small bodies of soluble salts under tropical humid conditions. However, this process can go much farther, judging by the Oligocene potash deposits of Alsace, which contain a humid forest and swamp fauna including very large butterflies.

The fauna and flora from the Alsace potash beds were studied by Quiévreux in 1935. Referring to the flora, he says (p. 174):

"From the general aspect of the flora we can conclude to a warm temperate climate of a temperature similar to southern Japan. We can also conclude to the existence of forests", and "a very marked dry season." ("De l'ensemble de la flore nous conclurons à un climat tempéré chaud dont la température serait à peu près celle du Japan méridional. Nous conclurons également à l'existence de forêts" . . . . saison sèche très marquée.")

In describing the fauna, Quiévreux mentions one bird, three mollusks, numerous spiders, butterflies, giant moths, mosquitoes, etc., which he interprets as a combined swamp and forest fauna of mixed temperate and tropical humid affinities.

Interpreting the fauna, Quiévreux says (pp. 179-180):

"This is a mixture of swamp and forest faunas. The swamp fauna is indicated by the Diptera and especially by the numerous Chironomides. But other insects indicate the presence of a forest, and this conclusion only corroborates that arrived at from the study of the flora.

"In brief, Alsace during the deposition of its potash was neither a desert nor a steppe. It was a forested country with water courses, and nothing indicates either the presence or the proximity of the sea." ("Le mélange d'une faune de marécage et d'une faune de forêt. Faune de marécage c'est l'indication donnée par les Diptères, en particulier de nombreux Chironomides. Mais d' autres insectes indiquent la presence d'une forêt, et cette conclusion ne fait que vérifier celle tirée de l'examen de la flore. Bref, l'Alsace n'etait ni un desert, ni une steppe au moment du dépôt de la potasse, c'etait un pays boisé avec des cours d'eau, et rien n'indique la présence ou le voisinage d'une mer.")

It seems then, that under certain favorable conditions of concentration the precipitation of soluble salts (including sylvite!!) can take place even in very large amounts under almost any quantity of rainfall, provided there is a definite dry season and an adequate physiographic setup.

Casts of crystals of soluble salts are infrequently found in the Triassic of the Connecticut Valley. Emerson (1895) reports cavities representing halite crystals, some of them filled with calcite, at West Springfield, Wilbraham and Holyoke, Massachusetts. Abel (1926) described as ice-crystals some casts which later proved to be gypsum. Glauberite has not been discovered as yet in the Connecticut Valley, but is reported as occurring throughout the Triassic of New Jersey and Pennsylvania (Hawkins, 1928; Wherry, 1916; etc.). It occurs throughout the entire Triassic section but only as isolated casts which do not exceed a frequency that can be satisfactorily accounted for by a mode of formation like the one operative in Cuba at the present time.

Glauberite has not been mentioned by Bennett and Allison. However, glauberite is less soluble than halite and is precipitated before halite from a solution. Gale writes (1914, p. 293):

> "Glauberite belong (s) to a class of less readily water-soluble salines... among the first to be deposited with the concentration of the water." '

Hence glauberite, as an indicator of evaporation, is less significant than halite.

The abundance of calcite in continental deposits has been frequently associated with a low precipitation. Such a broad interpretation is not in harmony with the general rule of the predominance of process over environment. It is also disproved by recently published descriptions of caliche-like calcite and silica layers from the humid tropics. Freise (as quoted by Sapper, 1935, p. 60) mentions large-scale rapid calcitization and silicication of soil material and sedimentary detritus in the coast ranges of Brazil in a region with a seasonal rainfall of 79 inches per year. The famous "Kankar" of the Punjab may occur not only in the Indian desert, but also in regions with a rainfall of 30 inches *if limestones form much of the bedrock.*[15]

Calcite is frequently and abundantly found at many places in the Connecticut Triassic. Usually it is definitely of intrastratal secondary origin and replaces feldspars to a considerable degree (in the way described by Gilligan). The introduced character of this variety of calcite becomes apparent from the fact that it occurs most commonly and abundantly at places where fissures favored the circulation of solutions: contact planes, fault planes, etc. Authigenic bar-

[15] The association of limestones with caliche deposits has been determined in a recent restudy of the caliche deposits of Arizona and New Mexico by Armstrong Price (1944). Also a typical Recent caliche deposit was discovered in central Pennsylvania on Ordovician limestone by P. D. Krynine in 1941 (unpublished observation). This deposit extends intermittently for several hundred yards along Spring Creek near Bellefonte. The rainfall of Centre County where this caliche deposit is located is 39 inches per year, uniformly distributed and the yearly temperature is 49° F.—a very humid climate.

ite also occurs at such places. Some of the calcareous cement, however, is of dubious origin. On a quantitative basis 80 per cent of the specimens examined (outside of the limestones) do not effervesce with acid and of the remaining 20 per cent at least three-quarters are definitely related to fissures and the calcite in them is of late, secondary origin (see Table 17). This secondary calcite is very abundant and conspicuous. It will be seen, hence, that not over 10 per cent of the specimens possess in very small amounts a calcareous cement of somewhat dubious origin. Nowhere does this cement suggest a caliche. Much of the calcite in the Triassic shales occurs as small secondary oval-shaped concretions (Plate XVIII-B) rather similar to the concretions of the Connecticut glacial clays described by Tarr (1935). In conclusion it can be said that the calcareous material of the Triassic sediments, while prominent and of frequent occurrence, is not of such type as to indicate a primary origin under sub-aerial semi-arid conditions. It is at best similar to the secondary calcite of the Siwalik beds.

The climatic significance of the limestone beds has already been reviewed in the section on black shales. It may be added, though, that Branner (1911) has described the extensive formation of a recent limestone in contemporaneous stream channels in the province of Bahia (Brazil). The climate of the area has been referred to as "semi-arid," but an examination of meteorologic data on the region, as supplied in Volume 3 of Köppen's "Handbuch der Klimatologie" (K. Knoch, Klimakunde von Sudamerika, 1930), discloses that the only weather station present within Branner's limestone area (Morro de Chapeo) has a rainfall of 35 inches per year and a mean temperature of only 66° F., i.e., its climate is definitely humid.

Possible Climatic Significance of the Lava Flows

The lower part of the lower lava sheet shows everywhere a pillow structure and in many places brecciated pockets of volcanic agglomerate which appear to be the result of local steam explosions. Both these features have been accepted as evidence that the eruption took place over a surface covered with water of varying depth (as judged by the different intensity of the phenomena mentioned above). A careful study of the sediments exposed under the lava shows that they are normal arkoses and conglomerates of fluviatile origin, most of which must have been sub-aerially exposed on interfluves at the time of the eruption. There is no evidence whatever of any lacustrine or even swamp deposits below the lava. Nevertheless, the surface of the basin was apparently universally covered with water, judging by the ubiquitous presence of the pillow structure.

A possible explanation is that the eruption of the lower lava took place at the height of the rainy season when the ground was en-

tirely water-soaked and covered with numerous puddles and pools. Such complete soaking is a feature of a savanna during the period of the rains: the surface of the ground then becomes a morass, absolutely impassable for any kind of traffic. Such thorough and complete soaking can best be accounted for if a heavy rainfall is assumed.

Evidence of Glacial Action

Since the days of Dana (1883), who once was somewhat partial to the idea of glacial activity in the Connecticut Valley Triassic, this possibility has received scant consideration. Recently Bain (1932) suggested the existence of a high glaciated mountain chain northeast of the Triassic trough in Massachusetts. His evidence is not conclusive, being based mostly on several scratched pebbles thought to be of glacial origin. The presence of high glaciers not very far away from the Triassic basin is not impossible, but is not in harmony with evidence bearing on the climate of the basin itself and its immediate vicinity. It would, however—if true—be a possible additional explanation of some of the unweathered feldspars of the Massachusetts Triassic. Nevertheless, inasmuch as Bain's structural interpretation of the Mt. Toby region and the hypothetical glaciated chain northeast of it has not been accepted, either by Professor Longwell or the present writer, it seems permissible to disregard any possible effects of glaciation on the Triassic of the northern part of the Connecticut Valley.

Evidence of Eolian Action

Barton (1916, p. 442) reports that in the Connecticut Triassic, some mudstones "show glazed surfaces." Smooth mudstones and shales are common at all horizons of the Newark. Their smoothness or "glazing," as Barton puts it, is however a very subjective thing, and does not appear to have been due to any marked eolian action. All the "glazed" surfaces seen in the Triassic can be explained as due to rapid drying of mud after superficial wetting. The same sort of thing is common today. At that, a certain amount of glazing by sandstorms over mudflats during the dry season on the savanna is far from impossible.

Pitted and frosted, perfectly rounded quartz grains have been discovered in very small numbers among the basal beds of the New Haven arkose at Roaring Brook and Dawson Lake. They may represent the remnants of an old sedimentary cover over the pre-Newark peneplane. When Triassic deposition began they were incorporated in the lowermost New Haven beds. Hence they are the products of an older climatic cycle and have no bearing upon the Newark climate. They may be even older, inherited from Paleozoic orthoquartzites.

Triassic Fauna

Character The fossils reported from the Connecticut Triassic comprise fresh-water shells, one insect, numerous invertebrate trails,

fishes, and terrestrial vertebrates. A listing of the different species and an interpretation of their probable habitat follow.

Mollusca. Two fresh-water forms, *Unio wilbrahamensis* and *Unio emersoni*, have been described from the upper part of the Triassic of Massachusetts. These shells point to the existence of somewhat permanent, rather slowly moving bodies of water.

Insects. From the Upper Triassic of Turner Falls, Massachusetts, and from Middletown, Connecticut,[16] comes *Mormolucoides articulatus* Hitchcock, which, according to Lull (1915, p. 33):

> "has been described as the aquatic larva of a neuropterous insect, hence again implying the presence of water of some duration. If the period of larval life was equivalent to that of the euphemerida of today, the water must have continued not one season alone, but three. This may,however, have been an annual insect the larval life of which would require but a transitory stream."

Invertebrate trails. Up to 52 species of invertebrate trails have been described by E. Hitchcock in his "Ichnology of New England" and the later supplements added to it. These species are distributed in the following way:

Hexapod Arthropoda, 8 genera, 24 species.
Inferior Arthropoda (including larval forms and worms), 10 genera, 16 species.
Mollusca, 4 genera, 6 species.
Questionable species, 5 genera, 6 species.

All these trails were undoubtedly formed by continental animals, but a review of the literature did not prove illuminating as to their probable habitat and preferred environment.

Fishes. Ganoid fishes occur in the black-shale horizons of the Meriden formation. These fishes have been studied by numerous investigators and the results have been summarized by Eastman (1911). Six genera and twenty species have been reported. These fishes, and especially their extreme abundance, indicate the permanence of many permanent water bodies.

Terrestrial vertebrates are represented by scarce skeletal remains and by numerous footprints. The vertebrate skeletons are all reptilian and represent four genera and eight species. They come from eleven localities and are well distributed stratigraphically throughout the Triassic. It may prove interesting to discuss them in chronological stratigraphic order.

In the New Haven arkose are found the remnants of phytosaurs and aetosaurs. The phytosaurs were "large diapsid reptiles, strongly resembling the Crocodilia in external form and habit." Also, they

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[16] Specimen from latter locality may not be in situ.

"were more or less aquatic, inhabiting the fresh water lakes and rivers of the Triassic period" (McGregor, 1906, p. 92). Their Connecticut representative was *Rutiodon* (*Belodon*) *validus*, which has been found at Simsbury. *Rutiodon* was about 12 feet long, and according to Lull (1915, p. 112):

"was further characterized by a long attenuated, gavial-like snout and slender conical teeth. Modern gavials of doubtless similar feeding habits are found in the large Indian rivers and in the Malay peninsula, Sumatra, and Borneo, and feed almost exclusively on fish.

"The presence of *Rutiodon validus* at Simsbury implies the existence during early Newark time of a large river or fresh water lake containing sufficient fish for the maintenance of animals some of which were about 12 feet in length."

The family Aetosauridae is represented by *Stegomus arcuatus*, the remnants of which were found in Fair Haven in a coarse-grained reddish arkose. The habitat of *Stegomus arcuatus* is rather obscure as yet.

Further skeletal remains occur only in the Portland formation. They include another aetosaur, and several dinosaurs. The aetosaur is *Stegomus longipes*, from Longmeadow, Massachusetts. This is a small terrestrial reptile, six times smaller than *Stegomus arcuatus*, and showing a distinct cursorial adaptation. The dinosaurs, most of them carnivorous, belong to the following genera: *Anchisaurus*, *Ammosaurus*, and *Podokesaurus*. They all are terrestrial forms. *Podokesaurus* was essentially a slender, cursorial, carnivorous animal.

Vertebrate footprints. In addition to the scarce skeletal remains, innumerable animal footprints occur in the Triassic. The earliest dinosaurian footprints are found in the lower Meriden formation, and they continue to the very top of the Newark series. As summarized by Professor Lull, the footprints represent 44 genera and 98 species. They have been found in enormous numbers; the collection at Amherst College alone contains 20,000 specimens, that at Yale University more than 10,000.

Most of the tracks occur in the Meriden formation and a considerable number also in the Portland beds. The Portland formation has been beautifully exposed by a series of large quarries from Portland to the north of Massachusetts. This may explain why it has yielded so many footprints while the comparatively poorly exposed New Haven arkose has yielded none. The Meriden formation is replete with footprints, as could be seen during the construction of the tunnel at the North Branford reservoir. This is easy to understand, for conditions of relative stagnation and relatively slow movement of water were then prevailing and much fine-grained plastic material, favorable for footprints, was deposited (51 per cent of section). During Portland time the conditions were less favorable than in the Meriden, but still much more favorable than during New Haven time (30 per cent of siltstones and shales in the Portland forma-

tion against only 15 per cent in the New Haven arkose). The main factor, however, seems to be the large amount of quarrying done in the Portland beds.

A quantitative study of the relative abundance of footprints is possible from the section through the upper Meriden formation at the North Branford reservoir tunnel, described in detail by Thorpe (1928), and reproduced on page 67. There 344 1/2 feet of strata are exposed, 49 1/2 feet of them bearing footprints (12 1/2 feet in reddish arkoses and siltstones, 17 1/2 feet in black and dark-gray arkoses and sandstones, 5 feet in red shales, and 14 feet in black and dark shales). An analysis of the relative ratios is given in Table 3. It will be seen from this section that where conditions are most favorable for the preservation of footprints (as in fine-grained clastics) the percentage of track-bearing beds becomes high (50 per cent in the red shales, 28 per cent in the black shales, 22 per cent in the dark-gray arkoses, and 12 per cent in the red arkoses). Probably the relative percentage of footprints assigned to the finer clastic should be higher, for not infrequently, while a print is in a coarse sediment as a whole, its formation is due to the presence of a very thin layer of tenacious clay coating at the very top of the sandy layer.

Significance. The fossil remains found in the Connecticut Valley can be divided into two groups: those belonging to animals whose habitat is pretty definite and those pertaining to species whose habitat is debatable or obscure. Among the first are the fishes, *Rutiodon*, and *Mormolucoides*, all of which indicate large permanent water bodies. To the second group must be assigned practically all the other fossils. The abundance of footprints and the great scarcity of skeletal remains has led to the unfortunate necessity of basing many of the interpretations on evidence of footprints alone.

Lull states that the number of species represented by footprints is 98. Abel (1926) questions this number, indicating that in the same species differences in footprints due to age, sex (i.e., weight), speed of running, etc., may be mistakenly accepted as indicating different species. The argument is interesting, but of no particular bearing upon paleoclimatic interpretation, for the abundance of individuals rather than of species appears to be the important point in determining the amount of the necessary food supply, and hence of the probable climate.

According to Lull (p. 34), most of the footprints are to be considered as favoring arid conditions:

> "From the compact type of foot, long stride, sometimes suddenly lengthening marvelously, and the narrow trackway of the many species, it can be easily seen that the character of speed and great traveling powers imposed by the desert was here at a high premium. . . . Bipedality among lizards of today is, so far as I am aware, confined to denizens of semi-desert environment. . . . That water was rare and at a premium when the rains did come is evidenced by the frequency of the association of rainprints with the dinosaurian tracks and the above mentioned mudcracks which followed the passage of the animal."

However, the fact that the celebrated *Tyrannosaurus rex*, together with many other bipedal dinosaurs, lived in a humid environment indicates the necessity for revising this interpretation. It may be that bipedality among carnivorous dinosaurs is only a convenient fighting posture, regardless of habitat. On the other hand, Raymond (1927, p. 244) interprets the faunal evidence thus:

"Now it is obvious that the carnivores could not have fed entirely upon each other, hence a large herbivorous population, very much larger than the flesh eating one is indicated and these animals must have been abundant because of the abundance of vegetation. A semi-arid region could not have supported the population indicated by the footprints in the Connecticut Valley, and it is very unlikely that so narrow a valley had one climate and the adjacent highlands, which were not mountains another. . . . The abundance of carnivores was probably as great an incentive to the acquirement of bipedality in running as would be the necessity of travel for water."

In addition, in his discussion with Glock, Raymond (1927, p. 158) suggests that the carnivores, being more active and travelling much more than the herbivores, would be liable to leave more tracks outside of the vast grasslands where the herbivorous population resided and where tracks could not form very well. The discovery by Thorpe (1928) at the North Branford reservoir of *Eubrontes giganteus*, apparently an herbivorous dinosaur 20 feet long, lends weight to the presumed existence of a large herbivorous population which, on account of its sluggish way of life, may have left fewer footprints on the mudflats along the shores of streams than did the fast-travelling and active carnivorous animals.

This introduces the necessity of evaluating the footprints on a quantitative basis. The footprints are extremely abundant and the ratio of track-bearing layers is also high. (See Table 3 and preceding pages.)

Such an abundance of footprints naturally suggests an abundant fauna. An objection to this is, that a single animal may leave a very large number of footprints on a wet mudflat (Davis, 1898, p. 36). This, however, is only partially true when applied to the thin, quickly drying mud layers of the Connecticut Triassic. An animal would have difficulties in leaving more than one or at most two, trails upon such a quick-drying mud layer. We find, however, at many places in the Triassic section serried batteries of footprints, trail next to trail, in very great numbers, all upon the same horizon. This suggests that, at least at certain localities, animals were very abundant. It does not prove, however, Raymond's idea of a very large animal population in the valley as a whole. It might have been that the great abundance of footprints at certain localities indicates only that the animals were congregating around water holes (as they do in Africa) and that they were far less teeming over the whole area than Raymond would suppose. This congregating may have easily taken place during the droughts of the rainless season. On the other hand, during the dry season the mudflats probably would be hard and dry

and could receive footprints only with difficulty. The thinness of most of the Triassic mud layers suggests (but does not conclusively prove) that the footprints were made between rains rather than during long periods of drought on a slowly drying thick layer of mud. This would permit an interpretation of the numerous footprints as evidence of a roaming and abundant fauna. Among such a fauna the presence of a large herbivorous population to support the numerous carnivores remains a necessity.

Professor Huntington (personal communication) suggests a method to solve this question somewhat similar to Raymond's way, namely, to find among the climates under which arkoses and red beds can form, one capable of providing a sufficient amount of vegetation to support these dinosaurian hordes *all the year round*. It must also be remembered that some of these creatures were of very large size and probably needed considerable food. Approaching the problem from this angle, it will be readily seen that the climatic classifications current among geologists (Barrell, 1908; Blackwelder, 1917; Twenhofel, 1926 and 1933) are entirely too schematic to be of much use. On the other hand, Köppen's classification (1930), although well nigh perfect, is much too complex and involved to be used successfully in this particular problem. An adequate classification, simplified after Köppen, has been devised by Huntington (1933), and is used in abbreviated form in the following paragraphs.

It is not difficult to see that arkoses and red beds can form in large quantities in only a few climatic environments, such as:

1) Wet and dry low latitudes (savanna) closely adjoining a hilly, wet tropical region.
2) Deserts (red beds must be imported, not of local derivation).
3) Regions of Mediterranean type (such as the Great Valley of California.).

[17] A description of the size of the animal population found on a present-day savanna should prove to be interesting. Quoting Huntington (1933, p. 246):

> "The grassy plains and hills of the Wet and Dry Low Latitudes are the El Dorado of animal life, especially in Africa. The tall and abundant grass supports millions of herbivorous animals such as antelopes of all sizes from little creatures no bigger than a cat up to the great hartebeest and gnu. These in turn provide food for thousands of fiesheaters, including the lion of Africa, the tiger in Asia, and the jaguar in South America. Here roam enormous herds of striped zebras, and longnecked giraffes among which ostriches with waving plumes may often be seen. The dangerous African buffalo charges the hunter suddenly out of a screen of grass. Elephants, in spite of the ivory hunters, can still be found in large numbers. Along the rivers the hippopotamus divides his time between land and water, and crocodiles sun themselves on the banks. Jackals and vultures live on the bodies of dead or dying animals. The photographs taken by men like Martin Johnson prove that the extraordinary big game stories of explorers and travelers from Livingstone to Roosevelt are not fantastic."

4) Chinese monsoon region.
5) Temperate grasslands, if in a piedmont zone (with difficulty).

Among all these possible choices, there is only one region that can make any substantial claims as to its capacity to support a large animal population all the year around, especially if this population is cold blooded. This region is a savanna (wet and dry low latitudes).[17]

To be quite fair, it is necessary to mention that the early reports give glowing descriptions of the animal life that teemed in the semi-arid parts of California before the advent of the white man. The California fauna, however, did not include any very large herbivores comparable in size to *Otozoum* and *Eubrontes*. On the other hand, present-day mammals probably consume more food than dinosaurs of equal size, for the sluggish habits of large reptiles reduce their food requirements.

This discussion shows that an interpretation of the Triassic climate based on animal footprints is controversial and inconclusive. It is possible to harmonize the footprints either with a semi-arid or a savanna climate. Of these two hypotheses the second one (savanna) appears, however, to be more credible, for it is based on simpler reasoning and a less subtle interpretation of facts.

In conclusion, the following inferences may be drawn from the Triassic fauna of the Connecticut Valley:

1) Some of the fossils are aquatic (fishes, *Rutiodon*, *Mormolucoides*) and indicate large and permanent water bodies.

2) The habitat of the other animals has not been positively proved and is open to discussion. Some of them, however, are extremely large herbivorous forms.

3) The total numbers of the animal population cannot be conclusively demonstrated but appear to have been great. In order to support such a large reptilian population all the year around, an abundant vegetation and a uniformly warm climate are indicated.

Triassic Flora

Description. Plant remains are widely, but sparsely, distributed in the Triassic of Connecticut. Fossil wood can be found from the dark arkoses at Forestville (approximately 1,500 feet above the base of the lower New Haven arkose) up to the very top of the Newark section along the plane of the Great Fault at any number of places from East Portland to Lake Quonnipaug. In the Pomperaug valley large silicified tree trunks (25 x 50 cm.) are present near the base of the formation, almost but not quite in situ. But, if fossil plants are

found practically at all horizons of the Newark, they occur in great numbers only in the dark shale members of the Meriden formation. Davis and Loper give the following list of plants from these shales:

1) From the "anterior" shales (lower Meriden formation):
   Conifers—3 species
   Cycada—3 species
   Equisetales—1 species
   Ferns—1 species
   Calamite-like stems with head
   Loperia carolinensis, a plant "probably monocotyledonous, perhaps aquatic" (Newberry, 1888)

2) From the "posterior" shales (upper Meriden formation):
   Cycada—4 species
   Equisetales—1 species
   Loperia carolinensis

Since Davis's time, it has been shown that the black shales of the upper Meriden formation ("posterior shales") do not form one single narrow horizon, but are spread over several hundred feet of strata. M. R. Thorpe (1928, p. 285) thus describes the flora collected from the site of the North Branford reservoir.

"The remains of vegetation collected at the site of the dam and in the Sugar Loaf Tunnel were submitted to Dr. G. R. Wieland. There are three horizons: the black shale (Horizon DB) at the dam, the tough gray sandstone (Horizon TA) at the West Portal and, much higher in the series, the black shale (Horizon TH), about three-fourths of the distance easterly through the tunnel in ascending order. The first is characterized by what seems to be Loperia, the second by Baiera, while the uppermost horizon contains huge quantities of wood, but in a fragmentary crushed condition."

Outside of the black shales, plant remnants are few. Lull says (1915, p. 48) that:

"In addition to these plants of the black shale, certain footprint localities have produced ferns, as *Taeniopteris* in the gray sandstones of Mount Holyoke, and a very doubtful one described as *Clathropteris* at Mount Tom and at Gill, though Fontaine concludes that neither of these is *Clathropteris*, but probably *Dictyophyllum* or *Camptopteris*.

Field's Orchard quarry at Gill has also produced a cone which may be the conifer *Palissya*, and twigs of *Cheirolepis muensteri*. There is also a *Palissya*-like conifer impressed upon the gray shale from the Horse Race quarry at Montague. With the possible exception of the Mount Tom and Mount Holyoke specimens, these are all from localities in the upper series of sandstones and shales, and are therefore much younger than either the anterior or posterior shales."

Lull suggests that possibly plant remains are more abundant outside of the dark shales than has been thought so far (1915, p. 47):

"In this connection mention should be made of a small slab of gray shale, preserved in the Peabody Museum at Yale, from the footprint locality at the Horse Race, Montague, Massachusetts, one surface of which is covered by a mass of fragments of vegetation consisting in the main of twigs and stems of conifers. They are very distinctly seen because of the film of

carbonaceous material which still adheres to most of the impressions; but I believe that, if the carbon had not been preserved, or if a monotone cast were taken of the surface, the plant remains would hardly be recognized as such at all. This would account for much of the apparent dearth of plant remains except in the black bituminous shale bands in which oxidation has been carried to a relatively slight extent as compared with the red shale and sandstone strata."

Abundant, but poorly preserved remnants of what appear to be Equisetales have been discovered by the writer in the upper New Haven redstone in the gorge of the Quinnipiac River, near Cheshire Street (loc. 35).

Climatic Significance. The flora of the Connecticut Triassic has been interpreted as that of a semi-arid flood plain (Barrell, 1908, p. 214):

"The strong oxidation acting at the surface normally destroys all vegetable tissues before they become buried in the course of time below the deep zone of oxidation."

And also:

"The herbaceous types of vegetation, however, are the more common over the well-drained portions of truly semi-arid flood plains and the plant impressions recorded in the strata would frequently be of small size compared to the large and luxuriant vegetable forms of more rainy climates."

From these arguments it would be easy to conclude that the fossil record points to a semi-arid climate during most of the Triassic, the black shales representing either lake beds (Lull) or limited humid periods.

However, it is not difficult to see that a solution of the problem based upon Barrell's interpretation of the vegetation of semi-arid flood plains omits the possibility that essentially similar results and a very similar fossil record can just as easily be produced under a very humid tropical climate, providing that well-defined wet and dry seasons are present. There we have thorough oxidation instead of moderate oxidation. The presence of marshes 2,500 square miles in extent necessary to account for the black shales and their flora can also be easily understood in such a region.

Such a climate of the savanna type is observed in the tropics on the border line of rainy forest belts, or on the leeward side of trade wind belts. It is characterized by a constant high temperature and by a seasonal rainfall. In such a savanna belt conditions of great aridity prevail during the dry season. It is literally possible to die of thirst for lack of water during the three rainless months in a region where the rainfall is above 100 inches per year. The ground water table fluctuates considerably according to the season. Thus, atmospheric solutions can easily penetrate downward and deep oxidation and destruction of organic matter take place.

The dry season in the savanna belt does not permit the universal development of a thick jungle forest. Instead, there is a semi-xerophilous vegetation of grass and low shrubs with some drought-resistant trees, for the water table sinks deeply in the dry season. Along streams and lakes, however, a luxuriant and extensive vegetation of the forest type is to be found, but the soil under this jungle is still red. The fossil record of such a vegetative cover will hardly differ from that postulated by Barrell for the vegetation of a semi-arid flood plain.

In order to obtain more light on the subject the expert opinion of a paleobotanist was sought. In an oral communication Dr. G. R. Wieland made substantially the following statements:

1) The plant remains of the Connecticut Triassic are few in number and remote from the present flora as to character. Hence any interpretation based upon the flora must be cautious and cannot be considered to be absolutely final.

2) Keeping these limitations in mind, certain conclusions can be drawn on the basis of the available plant remains. These conclusions are:

a) Among the Triassic floras of the world, certain plants (small-leaved types) suggest aridity or semi-aridity (German Trias), other species (megaphalous types) indicate a humid jungle climate (Virginia Triassic), others finally suggest an intermediate environment (savanna). The latter are found (truly only in limited amounts) in the Connecticut Triassic outside of the dark shale beds (such as the fossil leaf recently discovered in the railroad cut near Branford).

b) The flora of the dark shales can best be accounted for by a humid climate with plenty of rainfall. It is improbable that such a flora could have existed along streams on a semi-arid flood plain.

c) The character of the flora suggests a warmer climate than the present one, not necessarily a tropical one, but possibly subtropical or very warmly temperate.

General Character of the Fossil Record

Conspicuous features of the Connecticut Triassic are:

1) An abundance of plant and fish remains in the dark shales.

2) An extraordinary abundance of animal footprints both within and outside of the dark shales.

3) An almost complete absence of plant remains outside of the dark shales and an extreme scarcity of skeletal remains anywhere (barely a dozen specimens known).

The locally abundant presence of plants and fishes and the innumerable footprints found almost everywhere suggest that the gen-

eral absence of fossils is due not to the original lack of life, but rather to the lack of preservation of its remains. This usually is the result of destruction by chemical decay before burial. Chemical decay takes place best in a hot and *humid* climate.

At the present time the most potent chemical action on the earth's surface is found in a tropical savanna with a heavy seasonal rainfall. The high temperature and the extreme humidity are very favorable for bacterial growth and the alternating, thorough soaking and complete drying of the ground also contribute to the very thorough oxidation occurring in such regions. Chemical action on a savanna is infinitely more potent than on a semi-arid flood plain where the low rainfall does not provide bacteria with enough moisture.

The reducing environment of the Meriden dark beds was very favorable for the preservation of organic remains. Unfortunately these dark shales have never been extensively quarried and have not been thoroughly searched for vertebrate remains by trained workers. It seems reasonable to predict that if such a search is ever made many pleasant surprises will be in store for vertebrate paleontologists, for of the entire Triassic section the Meriden swamp beds are the most logical place for skeletal remains to be preserved.

Probable Climate of the Newark Epoch

The total length of the Triassic period has been estimated at 30,000,000 years. The Newark epoch, which lasted apparently only during Upper Triassic time, was therefore much shorter. However, it possibly lasted for several million years. Many climatic changes may take place during such a long period of time. Nevertheless, as judged by the homogeneous character of the sediments, it seems that these changes must have been rather in the nature of fluctuations (possibly at times fairly pronounced) superimposed on a general climatic background.

It is suggested that this general background was one of a relatively high uniform temperature, and pronounced but seasonally distributed rainfall, a climate of the type found at the present in tropical and sub-tropical savanna regions. These conclusions are based upon the following facts:

1) Extensive red beds containing locally derived red detritus suggest strongly a warm and *humid* climate.

2) Widespread swamp deposits covering thousands of square miles in warm regions are not known at the present outside of humid districts.

3) Differential pre-diagnostic weathering of local sedimentary detritus and the interbedding of variegated, alternative fresh and decayed layers is a feature of sedimentation in a savanna or monsoon climate close to a rugged source area.

4) Large-scale arkose deposits can easily form and be preserved in an extremely humid climate if the rainfall is seasonal and an adequate highland topography is at hand.

5) The same is true of fanglomerates. Local red detritus and organic material within the fanglomerates themselves confirm this view.

6) The abundance of desiccation marks suggests a marked dry season.

7) Crystal casts of halite, glauberite, and gypsum also strongly suggest a marked dry season but are compatible with a rainfall of 50 inches or more if a hot dry season of at least two or three months' duration is a feature of the climate.

8) The structure of the lower lava sheet may suggest extrusion upon a thoroughly water-soaked land surface.

9) There is no satisfactory evidence either of glaciation or eolian action.

10) Part of the Triassic fauna indicates the presence of large permanent water bodies. The habitat of the rest is debatable or obscure. The total numbers of the reptilian population can be understood best if a warm humid climate is assumed to account for the large amount of vegetation necessary to support such a population, which included very large herbivorous forms.

11) The flora of the Connecticut Valley Triassic can best be explained by a warm humid climate of the savanna type.

The concept of a hot and humid savanna climate with a heavy but seasonally distributed rainfall thus accounts *for all the features* of the Triassic sedimentary record, and it does so without resorting to "an ingenious straining of nature's laws."[18]

Having established the climate and the general order of magnitude for rainfall and temperature, a somewhat closer determination of numerical values for these climatic components will prove to be a fascinating, if somewhat speculative task. Recognized as such, the following line of reasoning is offered:

1) Red soils, especially lateritic, can be accepted as evidence for a minimum temperature of 55° or 60° F. and a rainfall in excess of 40 inches per year.

2) Crystals of soluble salts are known to occur under a climate with a rainfall slightly in excess of 50 inches, a dry season of 2 or 3 months, and a mean temperature of 75° to 80° F.

3) Arkose deposits have also been reported from a region with a somewhat similar climate (mean temperature 80° F. and a dry season of 3 months) but with a higher rainfall (in excess of 75 inches). The relief of the folded tropical foothills where present-day arkosic detritus originates is very steep, but it is probable that the

[18] Quoting one of Professor Lull's forceful expressions (1915).

relief due to a fault scarp would be even steeper, thus possibly reducing the amount of water necessary to produce the same erosive work.

As a tenable supposition, it seems probable that a rainfall of 60 or 70 inches in the drainage area of the fault scarp would be sufficient to cut through vegetation and by rapid "vertical" erosion offset the chemical effects of a tropical climate. The elevation of the fault scarp was apparently quite moderate, but still it may have reached several hundred feet. Hence the rainfall in the valley itself may have been as low as 50 inches.

A savanna climate of that type—with a uniformly high temperature around 80° F. a totally rainless dry season lasting at least 3 months (and possibly longer), and a heavy rainfall exceeding 50 inches (and possibly much more) in the valley proper and in excess of 60 or 70 inches (or much more) in the erosion region of the scarp —seems to be entirely compatible with all the facts of the Triassic sedimentary record.

A rainfall of 50 inches must be considered as close to a minimum, but it may have been much higher. No difference, so far as the sedimentary record goes, would exist between an absolute rainfall of 50 inches and one of 125, or possibly 150 inches. There is, however, an upper limit, for when the precipitation assumes extraordinary proportions, of the order of 200 inches or more, the dry season usually becomes so abbreviated as to render the preservation of desiccation marks problematical.

CHAPTER VII

SEDIMENTATION AND PALEOGEOGRAPHY

INTRODUCTION

It has been shown in previous chapters that:

1) The Triassic basin of deposition was a trough formed by the subsidence of a wedge-shaped downfaulted block bordered on the east by a steep, but only moderately high, fault scarp. The surface of this trough possessed a westward slope sufficient to maintain a good drainage most of the time.

2) The source area of the Triassic, immediately east of the Great Fault, was made up of granitic rocks with subordinate metamorphic formations. Depending upon the degree of weathering suffered by the parent material within the source area, this material entered the basin of deposition either as fresh, coarse-grained arkosic detritus (quartz and much feldspar), or as a greatly altered, fine-grained kaolinitic and gibbsite-bearing lateritic clay, heavily loaded with red hematitic pigment.

3) The climate during the Newark epoch was probably hot and humid with a heavy but seasonally distributed rainfall and a marked dry season.

These structural and climatic data, coupled with the testimony provided by the lithology of the sediments, make possible a reasonably accurate reconstruction of the processes of sedimentation believed to have taken place in the Connecticut Valley during Newark time.

Modern Analogies for the Triassic Basin of Connecticut

Difficulties of Comparison

Inasmuch as the present is the key, or rather the clue, to the past, it is usual, when commenting upon conditions thought to have existed in former times, to provide as an illustration some suitable analogy from the recent. Sometimes a certain association of structural and climatic features believed to have occurred in the past can be exactly duplicated in the present. More often, especially if those conditions were highly specialized, they may be duplicated singly, but not as a combination. Then, in order to be valid, a comparison between the past and the present must be properly qualified as to what elements are being compared—i.e., structure, climate, topography, or lithology.

The Great Valley of California and to a lesser extent Owens Valley and other parts of the Great Basin are the favorite modern

analogies of the Newark basin offered in the literature. Great red arkosic alluvial fans are a common feature both of the Great Valley and the Newark basins; fanglomerates and arkoses in a faulted basin of deposition seem to connect the Basin Ranges with the Triassic of Connecticut. These features are superficially comparable, but a brief analysis will show that any further general extension of the analogy between the Connecticut Triassic and the California basins—for instance as to climate—can be made only with the greatest of caution. The reason for this is, that the Great Valley of California and Owens Valley are not simple units, but are made up of several different elements (mountain slope and valley floor), each of these elements being a distinct structural, topographic, and climatic province. Furthermore, certain sedimentary features within these regions, apparently of recent origin, are really of Pleistocene pluvial age and bear no relation whatsoever to present climatic conditions.

The Great Valley of California

The Great Valley basin[19] consists of:

1) The western slope of the Sierra Nevada, a wide (40 to 70 miles), moderately rugged region with a seasonally humid climate (rainfall 25 to 100 inches per year, with an average of 40 to 50 inches).

2) A broad, flat, semi-arid valley floor.

The red detritus which forms the alluvial fans of the semi-arid valley floor originates in another climatic province among the red soils of the humid slope of the Sierra, from 25 to 100 miles away and from 1,500 to 5,600 feet above its place of deposition. The redness of the sediments is acquired not in the semi-arid province, but in the humid one.

Owens Valley

Owens Valley, exhaustively described by Knopf (1918), is a graben bordered on the east by the precipitous slopes of the Inyo Range and on the west by the even bolder and higher eastern slope of the Sierra Nevada. These mountains tower from 5,000 to 8,000 feet above the valley floor. The width of the slope from mountain base to mountain top is from 6 to 12 miles. Some alluvial cones begin only 4½ miles from the Sierra Nevada crest. The climate of the Inyo Range, valley floor, and eastern slope of the Sierra is arid (3 to 6 inches of rain per year). However, the drainage of the eastern slope of the Sierra receives a considerable amount of water from some of the heavy precipitation about the Sierra crest (up to 40 inches), part of which passes the summit and feeds the glaciers and headwaters of streams of the eastern slope. This is a somewhat unique set of conditions, and when discussing erosion and sedimentation on the eastern slope of the Sierra Nevada, it is well to remember that these processes

[19] For original descriptions see the works of Kirk Bryan, Knopf, Reed, and Lawson.

are the result not only of the arid climate of the regions, but also of the large volume of water which enters the valley from the Sierra Nevada.[20]

Knopf summarizes the situation thus (pp. 9 and 10):

"The drainage of the region is derived almost wholly from the Sierra Nevada. . . . The great alluvial cones that flank the mountains between which Owens Valley lies constitute one of the most striking features of the region. Their development differs notably on the two sides of the valley; along the Sierra Nevada they overlay and form a continuous alluvial slope that merges almost imperceptibly into the valley floor, but along the Inyo Range they occur only at the mouths of the canyons and are distinct topographic units which stand out in bold contrast to the level floor of the valley."

These alluvial cones of Owens Valley are not red; they are gray or brilliantly white. In many places they contain enormous boulders, up to 50 feet in diameter. Boulders 18 by 8 feet have been transported 5 miles and boulders 4 feet in diameter form prominent terraces 7 miles away from the Sierra Nevada (Knopf, p. 53). Such extreme coarseness and widespread extent of the coarse material can be accepted as good evidence for very high relief and to some extent for a very marked dry season, possibly even aridity. No fanglomeratic alluvial cones of comparable extent, color, or coarseness exist in the Triassic of Connecticut. The only comparable point between Owens Valley and any Newark basin is the presence of a border fault scarp. The character of the detritus, and hence the probable relief and climate cannot be compared at all.

[20] This is an important feature which has been frequently overlooked when discussing sedimentation in an arid climate. Many of the American deserts used as illustrations of sedimentation under arid conditions are really freak deserts. It is true that they receive a very scant rainfall in their depressed portions, but the volume of water which enters these ultra-arid basins and controls sedimentation therein comes from a relatively considerable precipitation on the adjoining high mountain slopes. Nevertheless the inference is frequently made that the rapid and powerful sedimentary processes which take place in these basins are caused by the very small rainfall (1 to 5 inches per year) observed on the floor of these deserts. In reality sedimentation is the result of the precipitation on the mountain slopes and near the mountain summits, where it almost invariably reaches at least 10 inches per year, even in the most arid spots of the Great Basin, and usually exceeds 15, 20, or 25 inches and more. When precipitation is really low—as in the Sahara, a true desert—, then sedimentation is considerably slowed down, and often brought to a standstill.

To make matters worse, many of the sedimentary deposits found on the floor of the desertic basins of the arid American Southwest are not at all the products of recent sedimentation under arid conditions. They were formed instead, barely 20,000 years ago, during the humid, pluvial period of the Pleistocene and have been, time and again, mistaken for recent deposits. This has led to much confusion in the literature and all statements as to "arid" sedimentation in the young American deserts must be regarded with considerable suspicion until positive proof is offered that the sediments in question are the product of a recent and not of a fossil cycle of sedimentation.

Sedimentation in authentic old deserts, i.e., with no pluvial Pleistocene interludes, has been and still is—extremely meager, at many places almost nonexistent.

Partial Analogy Only Between the California Examples and the Triassic Basin of Connecticut

In order to compare properly recent sedimentation in the California basins and Triassic sedimentation in the Newark trough (Fig. 36) it would be necessary, first of all, to turn the Sierra Nevada at an angle of 180° so that its faulted eastern slope would face west, thus receiving the heavy rainfall of the present western slope. Then the height of the Sierra should be reduced from five to ten times, to an altitude of 1,500 feet or less. This new, relatively low and very narrow, but steep and rugged slope would then replace the present long and only moderately rugged western slope of the Sierra. It still would have to receive the same amount of precipitation (40 to 50 inches) in order to provide the same red detritus as does the present slope. The low elevation and narrowness of the new slope (probably even narrower than the faulted slope of Owens Valley) would unite it into *one single climatic province* with the lowland where the red alluvial fans were forming.

If these qualifications are provided, the sedimentary processes of the California basins can be used as a good illustration of the sedimentary processes of the Newark period. It should also be kept in mind that probably the temperature of Newark time was higher than the present temperature of California. A simpler and more effective illustration of Triassic sedimentation can be obtained simply by transplanting an active basin range into a region with a savanna climate.

Triassic Sedimentary Processes

The different lithologic types of the Connecticut Triassic are due to variations of one fundamental sedimentary process: rapid erosion and deposition under a savanna climate.

Erosion was taking place in the region of a steep, moderately high, narrow, periodically rejuvenated fault scarp. Numerous V-shaped canyons provided the fresh, coarse granitic detritus from which fanglomerates, conglomerates, and arkoses were derived. The upper, gentler slopes of the canyons, especially the flattish interfluves, supplied partially weathered (iron-coated) sand grains and deeply decayed, red, gibbsite-bearing clays, for in these portions of the fault scarp erosion was less active and chemical decay prevailed. As shown by Sapper (1935) and Krynine (1935), in tropical regions of youthful or rejuvenated topography most of the erosion takes place *within* the canyons. Hence a large predominance of fresh over weathered material, of coarse clastics over fine clay, and of pale-colored over red detritus is to be expected. These expectations are confirmed by Table 3 and Figures 16 and 17 which summarize the lithology of the Triassic of Connecticut.

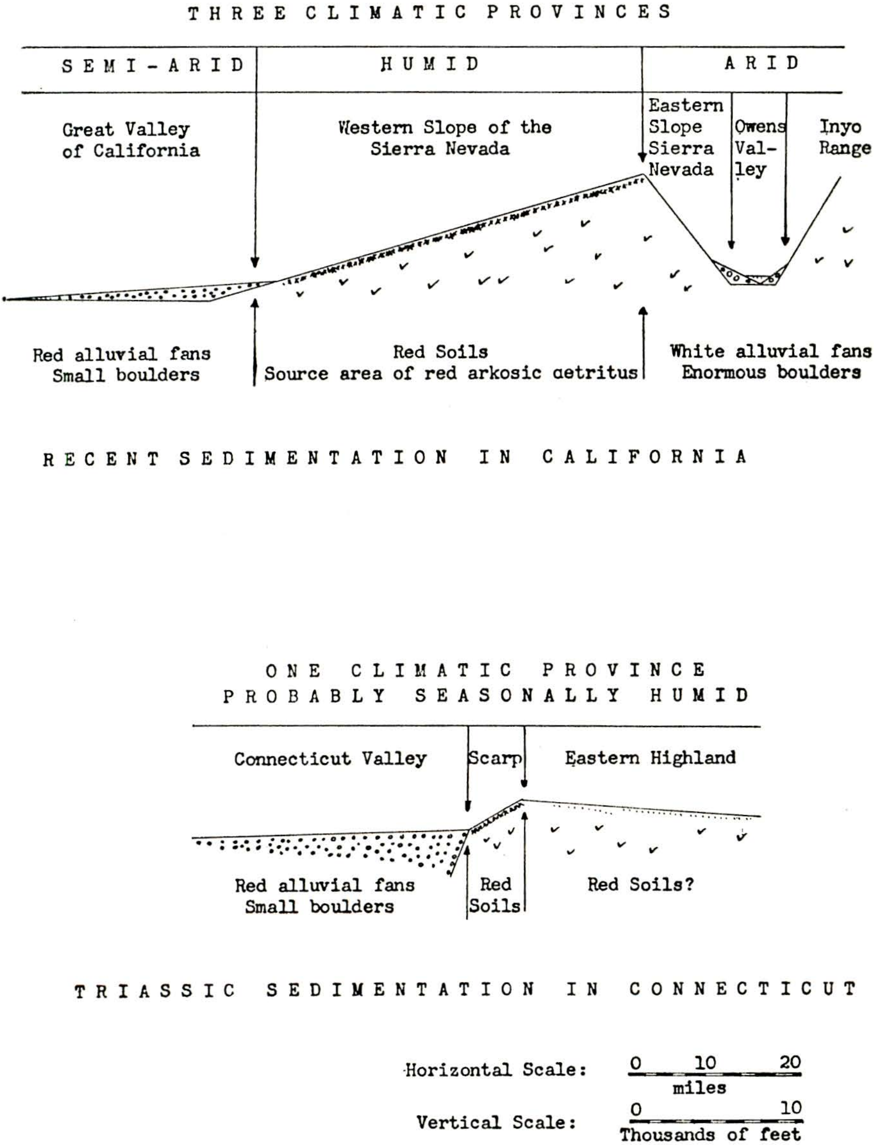
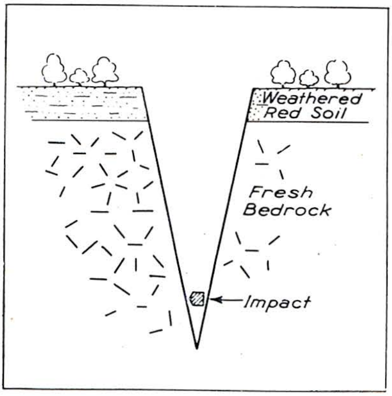


Figure 36. Differences between formation of recent red beds in the Great Valley of California and the formations of the red Triassic arkoses of Connecticut. Note marked differences in relief and distances to be covered by detritus in both regions.

The contemporaneous existence of two different loci of weathering (with the possible mixing in all proportions of the resulting detritus) is evident from the occurrence, side by side, even within the same thin section, of many different stages in the weathering of one single mineral species; or even more forcibly, by the simultaneous existence, again in the same specimen, of fresh pieces of such utterly unstable minerals as biotite, orthoclase, or even augite and of deeply weathered and decayed fragments of such a relatively stable mineral as microcline.

This difference in the total amount of chemical alteration suffered by the parent material coming from the interfluves of the Great Fault scarp as against the detritus originating from the canyon bottoms of the same scarp, is due to the fact that while *intensity of chemical decay* was identical in both these two loci of weathering, the *time available for chemical decay* to do its work was infinitely shorter at the bottom of the canyons than along the flattish interfluves (Figures 37, 38, 39).



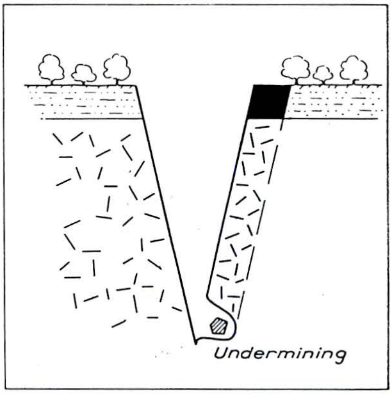


Figure 37. Left. First step in the formation of the Newark detritus: A double locus of chemical weathering (intensive on the interfluves at the top and almost nonexistent within the canyons at the bottom) and concentration of the physical erosion (vertical or linear type) at the bottom of the canyons through impact of boulders against walls. Intensity of chemical action on interfluves was adequate to produce gibbsite (lateritic weathering) and hematitic concretions. In contrast, minerals from the canyon bottoms are brilliantly fresh.

Figure 38. Second step in the formation of the Newark detritus: Undermining of the canyon walls (through impact, etc.) loosens up a large segment of the wall composed mostly of (under conditions of steep topography) fresh granitic detritus, since chemical decay and the formation of red soils (solid black) take place only on the flattish interfluves.

If relief gets gentler (through failure of fault scarp to rejuvenate itself) the proportion of red clayey detritus may increase considerably (as in Meriden time). The same mineral (such as microcline) will be fresh if coming from the canyon bottom and altered if coming from the interfluves. Such a mixture can be seen in a single specimen (see Plate XXIX).

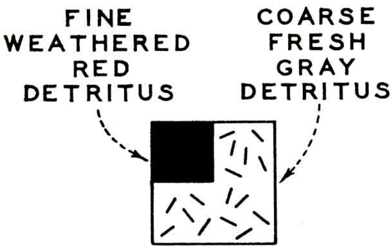
Sorting and differentiation of this mixed detritus were functions of the precipitation. Short, but violent cloudbursts which usually characterize the beginning and the end of a rainy season were probably sufficient to transport pell mell the jumble of unsorted material from the canyons into the region of the sharp break in slope at the foot of the scarp, and thus fanglomerates were formed. The longer, but equally violent cloudbursts, a feature of the middle of the rainy season, swept the material past the apexes of the fans and, giving rise to superfloods, distributed it over the valley. Conglomerates and arkoses were deposited within the channels, which upon lateral migration and coalescing produced apparently horizontally extensive sandstone layers. Silt and clay, dropped down at the tail end of these floods over the basin's interfluves, formed the real siltstone and shale layers (Figures 40 and 41).

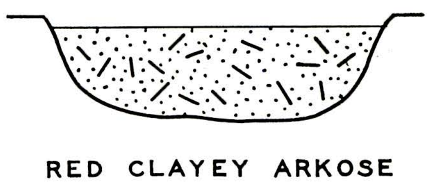
A decrease in gradient, and hence in velocity and transporting power of the streams as they flowed westward, explains why there is a general tendency of the sediments to decrease in coarseness from east to west. This tendency is shown on Figures 8 and 9 and has been mentioned in the discussion of the relations between the Redstone and Lamentation types of New Haven arkose.

The phenomena of fluvial transport and deposition were essentially similar to those of a recent tropical piedmont. The arkosic sediments were rapidly covered up and thus removed from the influence of post-depositional decay which affected only the upper layers of the older gravels exposed in interfluves where development of red soils, iron coating of sand grains, and even formation of small ferric-oxide concretions of the "perdigon" type (Plates XIX-A and XXIX-E) were taking place. During the dry season dessiccation marks appeared on mudflats, and crystals of soluble salts were formed. The extremely thorough oxidation of such a savanna environment resulted in the almost complete destruction of all organic remains. Footprints had a much better chance of survival than organic remains.

The different horizons of the Triassic possess different ratios between coarse and fine, fresh and decayed, oxidized and reduced material (see Chapter IV). These changing ratios were mostly due to changes in topography and hence were a consequence of the structural movements that were taking place during Triassic sedimentation. When accelerated faulting resulted in a sharp rejuvenation of the Great Fault scarp, the relief in the region of erosion became much higher and steeper. Immediately conglomerates became abundant and spread westward far into the valley. This apparently is what took place at the end of New Haven time shortly before the eruption of the lower lava. The Foxon Park, Russo Street, East Rock, and Wallingford conglomerates bear witness to this.

Deposition on a non-reducing piedmont slope was normal for the Triassic. The slope was the product of a balance between the depression of the basin's surface due to the sagging of the bottom of the trough and the building up of the same surface through the influx of sediments. On several occasions this equilibrium was destroyed, drainage was impeded or made ineffective, and a reducing environment established. The most important and widespread of these disturbances happened during upper Meriden time when a too rapid subsidence of the valley floor, probably due to accelerated structural downwarping, reduced the slope of the piedmont and gave rise to extensive swamps. These swamps, although extremely widespread, were shifting and relatively impermanent. During the rainy season almost the whole valley floor must have been a boggy quagmire,





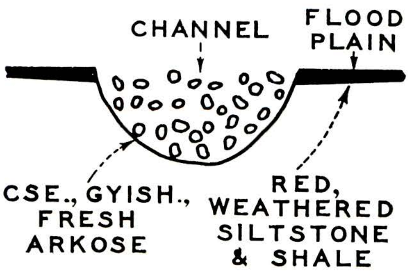


Figure 39. Left, above. Relative proportions of fresh granitic detritus (75%) and altered, red, gibbsite-bearing clayey detritus (25%) produced by erosion of the fault scarp under average structural conditions of the Newark. Compare Figure 17 for resulting rock types. These proportions change with the steepness and ruggedness of the topography, i.e., with the intensity of the uplift of the scarp.

Figure 40. Right, above. Third step in the formation of the Newark sediments: Pell-mell deposition of the mixed granitic and clayey detritus produces a red clayey feldspathic sandstone of the Redstone type.

Figure 41. Below. Fourth step in the formation of the Newark sediments: If deposition proceeds through cyclic floods, the detritus is unmixed all over again and separated into coarse, pale, arkosic sediment which makes up the deposits of the channels; and fine, red clayey sediment, which spreads out on the floodplain, forming red siltstones and shales on the interfluves between the river channels. See Figure 17 for all possible rock types produced by this process.

but many of the swamps dried out during the dry season. Possibly conditions were then similar to those that can be seen now on the lower coastal plain of Tabasco. In the reducing environment of these swamps black shales were formed, and many of the coarser sediments also lost their primary red color or did not acquire it after deposition. On account of the frequent changes in the position of these swamps the reducing environment did not last very long at any one place and dark sediments became interbedded with red ones. In Virginia the sagging was either more pronounced, or longer, or both, and in addition to black organic shales, coal beds were formed.[21]

Erosion in the meanwhile was still intermittently active in the region of the scarp. This is proved by the presence of fanglomerates and conglomerates interbedded with the upper Meriden dark shales in the vicinity of the Great Fault and as far west as the eastern part of the North Branford tunnel. However, this coarse material could be transported farther west only with difficulty because of the sluggish character of the streams slowly meandering in the swampland. This explains why the swamp beds generally consist of fine muds.

Much of the Meriden sediments outside of the dark shale horizons also consist of fine-grained clastics, red siltstones and shales (Table 3 and Figures 16 and 17). This suggests a marked decrease in erosive intensity during Meriden time, probably because the rejuvenation of the fault scarp was proceeding then with less than its usual vigor. As a result the average relief[22] of the scarp region became more subdued and chemical decay more effective. Fine red muds entered the valley, replacing to a large extent the coarser clastics, and the total volume of sedimentary detritus supplied by the scarp region became much less. As a result the construction of the piedmont slope was slowed down, the angle of slope was decreased, and the equilibrium between the sagging of the surface and its building up by sedimentation became so precarious that only a very little additional sagging was required to establish swamp conditions. The dark beds of Forestville (in the New Haven arkose) and of Middlefield (in the Portland formation) were also apparently due to impeded drainage caused by down-warping or possibly even by a simple damming action due to local excessive growth of some alluvial fan. The Forestville beds are local in extent, but the Middlefield dark shales are widespread, although much less so than the Meriden black shales.

The lower Meriden lake beds have been explained by Lull as due to a sudden damming of the drainage by lava flows. This view is supported by the fact that at many places the lacustrine deposits

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[21] The Virginia Triassic is discussed further along in this chapter.

[22] By average relief is meant the relief of the scarp region during most of Meriden time, i.e., between the shorter—or less pronounced—uplifts of the scarp when again bold relief and violent erosion were temporarily reintroduced.

rest directly on the lower lava sheet. This interpretation does not explain the absence of a similar damming action after the extrusion of the middle and upper lava flows. However, inasmuch as the different extrusions possibly came out of different fissures, their action upon the drainage may have been diverse. The first lava flow may have temporarily blocked the outlet from the valley, the others may not have done so. Another hypothesis would explain the lacustrine conditions of lower Meriden time by a simple pronounced depression of the land surface due to accelerated downwarping, a notable feature of Meriden tectonics. The writer favors this second, tectonic hypothesis but it is quite possible that both are correct, at least in part, and that the lower Meriden lakes were of compound origin.

Source Area and Drainage Pattern

The surface of the Triassic basin consisted of a piedmont slope built up by coalescing and dissected alluvial fans and floodplain deposits. The fanglomeratic portions of the fans did not extend more than 2,000 feet away from the fault. On the basis of their mineral composition it is possible to distinguish two major fans or groups of fans: the central Connecticut fan (Fig. 6) characterized throughout at all horizons by indicolite; and the southern Connecticut fan characterized by the absence of indicolite and the presence of other key minerals (epidote, and pink garnet in the New Haven horizons, etc.). The indicolite of the central Connecticut fan can be traced to a huge tourmalinized pegmatitic area east of Portland where indicolite occurs as a notable feature of the Strickland quarry (Schairer, 1933).

There is no intermixing of the material of these two major fans within the main Triassic area of the Connecticut Valley. This suggests that the drainage proceeded strictly in an east-west direction with no marked longitudinal pattern. However, two significant exceptions are found: once, at the very base of the Newark, when indicolite is found in southern Connecticut (Dawson Lake and Bethany Gap) and conversely, epidote and pink garnet are prominent in central Connecticut at Roaring Brook; and the second time, in the lower Meriden lacustrine beds when indicolite again appears in southern Connecticut (Northford limestone). These two horizons are precisely the ones at which such intermixing between southern and central Connecticut material is to be expected, for at the very beginning of Newark deposition the drainage pattern had not been definitely established as yet, and again during the lower Meriden lacustrine period the drainage pattern was destroyed and sediments moved freely to and fro along the valley. It appears, then, that there is no evidence of longitudinal drainage and hence of the presence of a master stream within the present main Triassic area.

In the Pomperaug area indicolite, epidote, and pink garnet are all present at the same horizon, this suggesting a complete coalescing of the fans and an intermixing of their sediments. In addition some

of the Pomperaug minerals possess certain varietal characteristics which have not been observed in the main valley area types. Finally, if allowance is made for the fluctuations in garnet content, and the frequencies of tourmaline and zircon are recomputed without the garnet percentage, it will be seen that these frequencies change slowly and gradually and in a way different from the corresponding changes in the main area. All this suggests that the Pomperaug basin was filled not only with material from the central and southern Connecticut fans, but also from another source which possibly may have been the sediment brought by a master stream. This stream, at least during New Haven time, must have flowed west of the Pomperaug area, for during this period material from the east was prominently present there. Some idea as to the position and character of this master stream can be indirectly derived from a study of the source area of the Triassic sediments.

Most of the sedimentary detritus which formed the Triassic rocks of Connecticut was probably derived from a region 3 to 10 miles wide (or less) east of the Great Fault scarp. A study of the original prismatic section of Figure 33 shows that a source area even 5 miles wide (and it was probably much narrower during much of Triassic time) and 3 miles high could hardly have supplied more than one-half of the sediments which filled the Triassic basin. However, if the movement on both sides of the Great Fault was not uniform but differential, then this difficulty becomes less. If the Eastern Highland was elevated 25,000 feet while the basin of deposition was depressed 16,000 feet, then the narrow scarp region becomes adequate to supply close to 80 per cent of the sediments of the basin or more. In addition it must be remembered that the part of the Triassic sediments which escaped erosion and is now available for study consists of the portion nearer to the eastern part of the basin, and as such, is evidently formed entirely of material locally derived from the east. The more central and also the higher parts of the section have been eroded away. These eroded portions are the ones which possibly were built up by an aggrading longitudinal master stream.

It is probable that early during Newark sedimentation the basin was filled mostly by alluvial fans growing from the fault and extending beyond the Pomperaug area, 35 miles west of the fault scarp. A coalescing and intermixing of the fans took place somewhere in the Pomperaug district. It is also possible that old streams were superimposed from the pre-Newark peneplane and cut across the fault. Such streams may have brought sediments from a region far beyond the Great Fault. However, there is no evidence of the presence of such superimposed streams in southern Connecticut, but this does not exclude the possibility of their presence farther north. Finally, a longitudinal master stream was probably formed soon after the opening of Newark sedimentation and aggraded the western and central part of the Triassic trough. It deposited material brought in by

itself, or by its tributaries (some of which may have been superimposed), or reworked the alluvium of the piedmont. The direction of flow of this master stream cannot be directly determined, but it probably was from north to south, this being suggested by the general paleogeography of Newark time, which favored a drainage toward the Atlantic, across the eroded debris of Paleozoic landmasses. During New Haven time the course of this stream was apparently west of the Pomperaug district. Its location during Meriden and Middletown time cannot be determined.

Relations of the Different Triassic Basins

A comparison of the lithology of the different Triassic areas of eastern North America (Nova Scotia, Connecticut Valley, New Jersey, Pennsylvania, Virginia, and North Carolina) reveals that all these areas are essentially similar, with the only lithological variations due to differences in the nature of the rocks of their respective source areas. Even brick-red feldspathic sandstones of the "Redstone" type are represented among the specimens from the Nova Scotia Triassic in the Yale Collection. It seems reasonable to assume that all these rocks were formed in a similar climatic and structural environment and were the product of very similar processes.

This statement needs some elucidation, for the idea is current among geologists that the Triassic areas of Virginia are lithologically different from those of New Jersey and Connecticut. The remarkable megaphalous flora of the Virginia coal beds, which leaves but little doubt as to a mesophytic swamp environment and a tropical humid climate, has been associated in the minds of many geologists with the impression that the Virginia arkoses are dark-colored or gray. It has also been said that red color, desiccation marks, and other features commonly associated with alleged semi-aridity are much less prominent in Virginia than farther north.

This is a conception not supported by facts. A study of the detailed petrographic descriptions given by Roberts (1928) shows that in Virginia the arkoses are about equally divided between red and gray, that 80 per cent of the shales are red (p. 40), that sun cracks, raindrop impressions, and fossil tracks are common or abundant (pp. 147, 158), and that coal seams are interbedded with red sandstones (p. 98). These lithologic descriptions and relative frequencies are identical with those of the Connecticut Triassic. Finally, the celebrated megaphalous flora becomes almost entirely invisible when looked for in field exposures outside of coal mine shafts. Roberts writes (p. 149): "Outcrops are so rare and so poor when found that they yield nothing." If this is correct, then the frequency of plant remains visible in the field within the Meriden swamp beds compares favorably with that of the Virginia Triassic. The presence of the

marvelous flora described from Virginia seems to be due less to an inherent difference between the Triassic vegetation of the Connecticut and the Virginia basins than to the prosaic fact that the Virginia plant-bearing beds have been well exposed by mining and trenching. Roberts (p. 149) deplores that:

> "The day of collecting in the Triassic coal area is past for no longer are prospectors interested in drilling or in sinking shafts. Fontaine probably collected the best material as to variety and preservation that can ever be collected again."

Wieland (personal communication) has expressed the opinion that the discovery of a good flora from the Connecticut Triassic cannot be expected until large-scale trenching of the Meriden black shales is attempted.

Hence, on the basis of both lithology and the fossil record it appears that the difference between the Virginia and Connecticut Triassic basins was not one of climate, but only of topography, and very minor at that. In Connecticut a slight warping depressed the land surface and formed shallow—or short-lived—swamps in which black shales and fragmentary wood were deposited. In Virginia a somewhat more pronounced—or longer—subsidence gave birth to deeper —or more permanent—swamps in which coal was formed. A difference of 20 feet in the amount of structural warping appears as sufficient to account for whatever difference there is between the Connecticut and the Virginia swamp beds.

Probable Newark Paleogeography of Eastern North America

It has been generally stated (Schuchert and Dunbar, Brooks) that the climate of the Triassic period was warmer than that of the present. The results of the present investigation, which tend to assign a tropical or sub-tropical climate to the Connecticut Valley, confirm these views.

If the climatic zones had been thus shifted toward the poles, it is possible that the Atlantic seaboard was brought past the horse latitudes and into the region of seasonal tropical rainfall. The heavy precipitation of the Newark could have been easily derived from the Atlantic Ocean. The nearness of the Atlantic can be inferred from the discovery of sharks' teeth in the black Triassic shales of New Jersey (as described by Bryant).

Environment and Landscape of the Newark Epoch

Central and western Connecticut during Newark time can be pictured as a wide flatland, bordered on the east by the steep but relatively low hills of the Great Fault scarp and to the west merging insensibly into the somewhat similar flatland of southern New York and New Jersey. The interfluve between these two basins may have

been so low as to lack any topographic expression, but it probably still was a divide between the two sedimentation basins of Connecticut and New Jersey. A master stream meandered over this flatland, probably flowing southward. Rapid deposition of material from the scarp region was building large alluvial fans and floodplains with a western slope, but continued subsidence of the basin due to eastward tilting along the Great Fault kept the surface almost flat, although a very small but still effective westward slope provided for adequate dissection and drainage. This equilibrium, however, was delicate, and as soon as it was disturbed in Meriden time, extensive lakes and swamps covered the flatland. This disruption was possibly the result of a damming action by the lava sheet immediately after the first extrusion, but probably due to more complex causes such as regional sagging of the basin surface due to structural warping some time after the extrusion of the thick middle lava sheet.

The climate was hot and seasonally very humid. During the wet season heavy, long-continued rains transformed the flatland into a vast, sticky, water-soaked morass. Torrential rivers, heavily loaded with coarse detritus, roared westward from the hills. The gentler rains reworked and transported the red clayey material and deposited siltstones and shales.

During the dry season a broiling sun was beating upon the Connecticut savanna, caking and cracking the red soils. However, dense and luxuriant forests extended for several hundred yards on each side of the numerous watercourses, providing food and a cool shelter for the reptilian denizens of the Newark.

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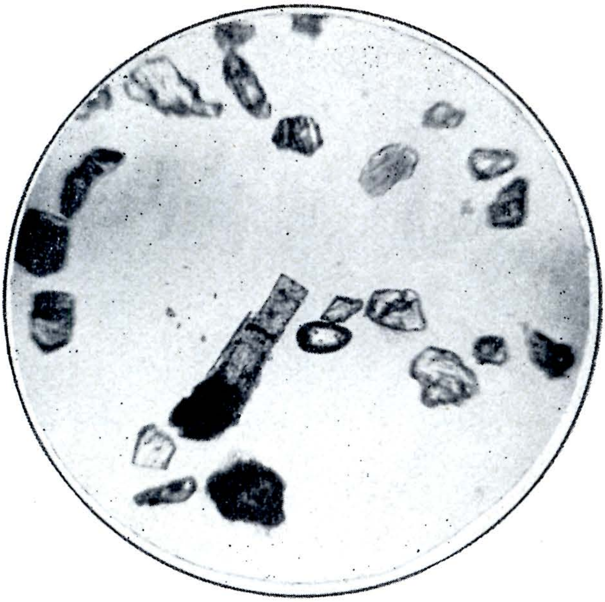
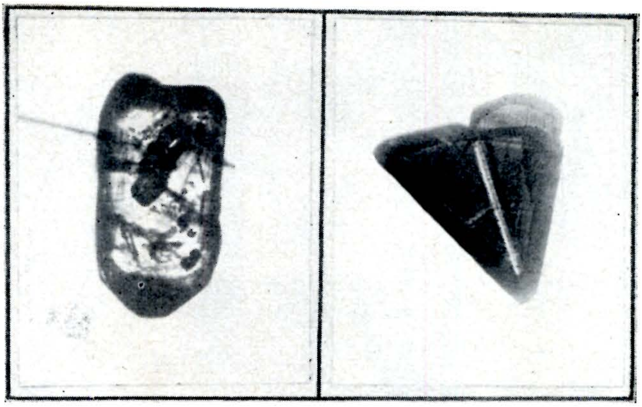
PLATE I



A.—Heavy residue from basal New Haven arkose (loc. 21A), showing kyanite (large fragment), garnet, epidote, zircon and tourmaline, X 47.

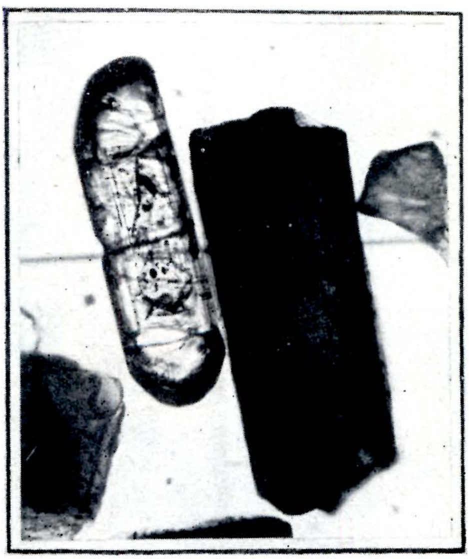
B.—Heavy residue from basal Meriden formation (loc. 11), showing anatase, barite, biotite, ilmenite, leucoxene, monazite, muscovite, tourmaline and zircon (see also Plate II a-D), X 36.

PLATE II



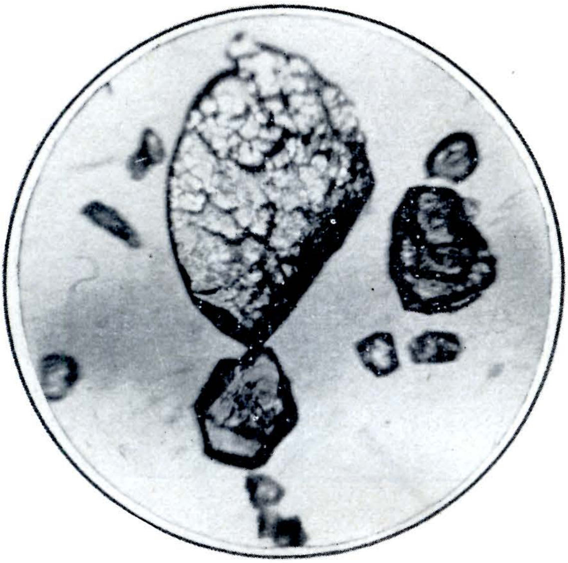
A.—(Left)—Zircon, subrounded (loc. 38), X 267.

B.—(Right)—Twinned purple rutile (authigenic?) (loc. 38), X 220.

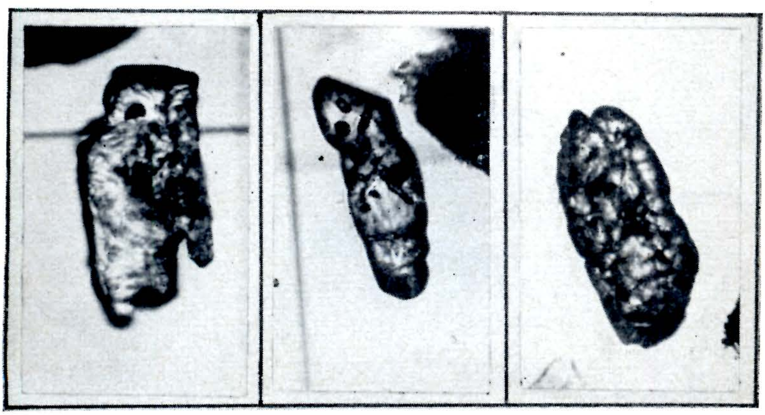


C.—Zoned zircon; foxy-red striated rutile (loc. 11), X 200.

PLATE IIa



A.—Pitted pink garnet and idiomorphic epidote (lower center) from basal New Haven arkose, loc. 21 (Dawson Lake), X 47.

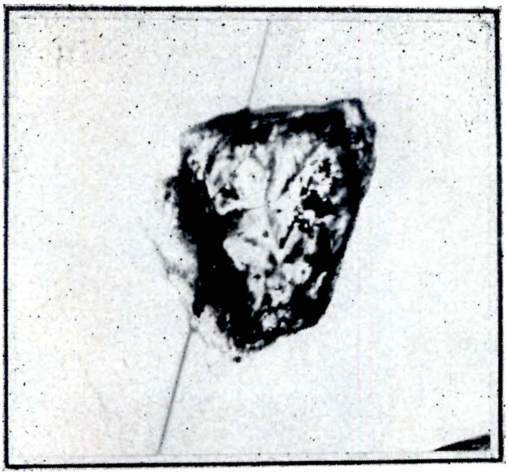


B.—(Left)—Broken (corroded?) garnet, lower Meriden arkosic beds near lava flow (loc. 11), X 145.

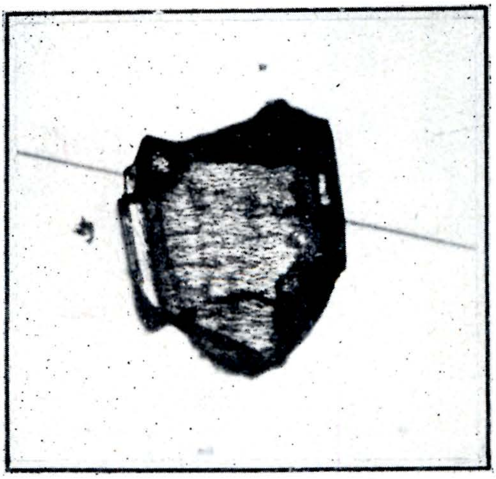
C.—(Center)—Broken zoned zircon, from lower Meriden limestone beds at Northford quarry (loc. 10), X 200.

D.—(Right)—"Potato shaped" zircon (broken and abraded along incipient zoning, possibly corroded?); this grain shown also on Plate I-B, Northford quarry, X 121.

PLATE III

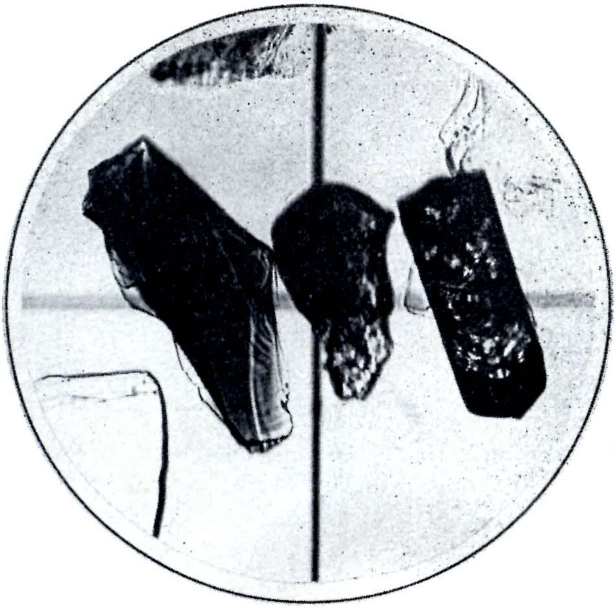


A.—Staurolite, from basal New Haven arkose, loc. 39 (Roaring Brook), X 215.

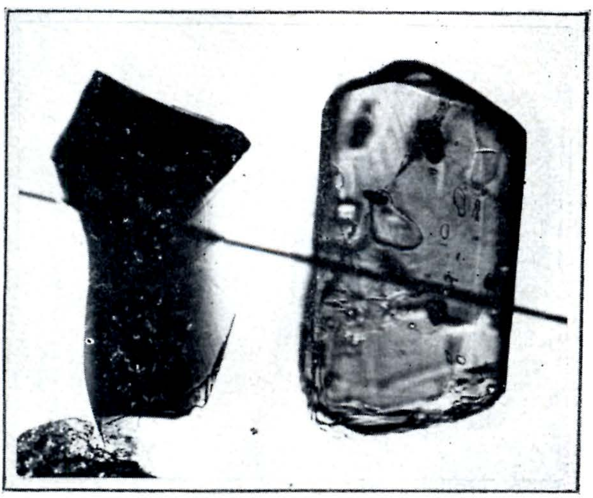


B.—Titanite from basal Meriden arkosic beds, loc. 11 (near Northford), X 152.

PLATE IV

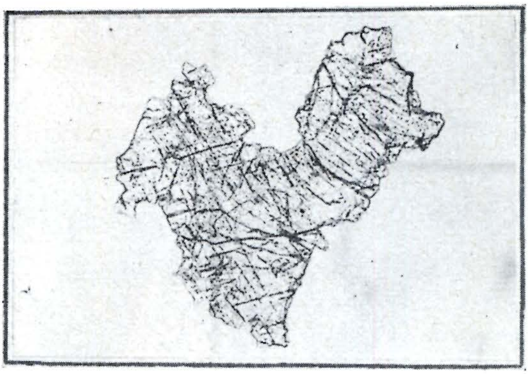


A.—Indicolite or deep-blue tourmaline (left), augite (center) and zoned zircon (right), against a background of large muscovite flakes, loc. 39, basal Triassic at Roaring Brook, X 146.

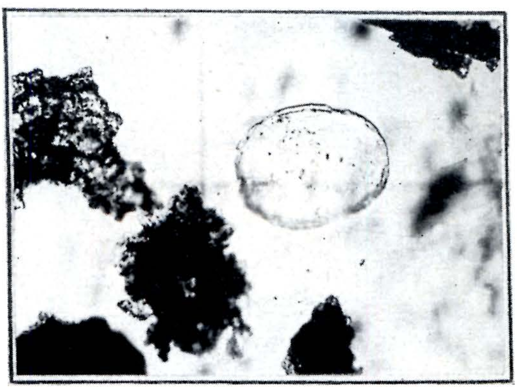


B.—Indicolite (left) and brown tourmaline (right). The indicolite is a fragment from a much larger crystal of pegmatitic deep-blue tourmaline. The brown tourmaline is an idiomorphic plutonic variety. Loc. 38, Roaring Brook, 75 feet above base of Triassic, X 140.

PLATE V



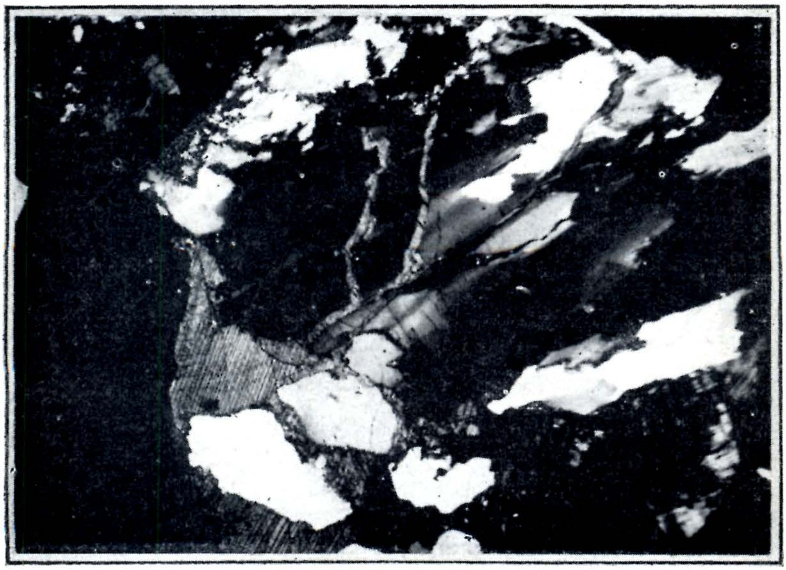
A.—Barite from the lower Meriden lacustrine beds of central Connecticut (loc. 30, Shuttle Meadow). Extreme irregularity of outline suggests authigenic origin as a pore filling. Inclusions are partly fluid bubbles, and partly carbonaceous matter. X 52.



B.—Well-rounded (coin-shaped) muscovite and irregular-shaped (authigenic) barite full of bubbles and carbonaceous matter, also from loc. 30. Rounding of muscovite suggests the existence of very gentle bottom currents. X 52.

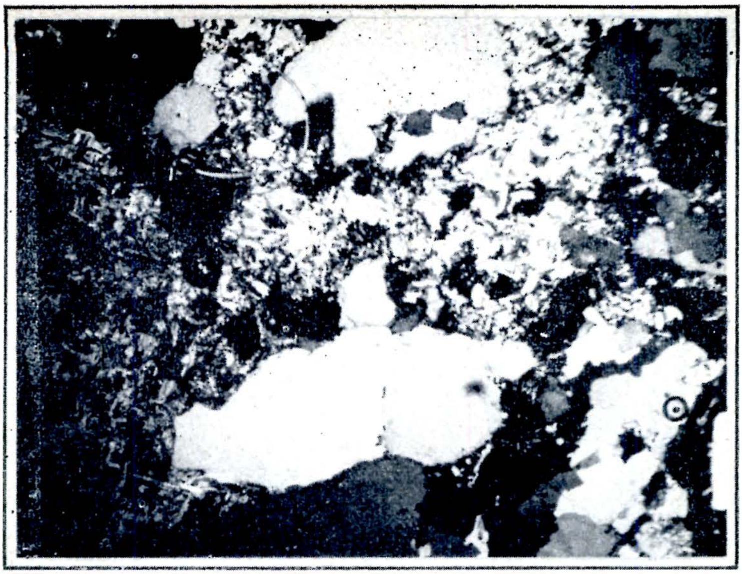
PLATE VI

A.—Fractured basal New Haven arkose at Roaring Brook (loc. 39), showing permeation by calcite which fills veinlets in quartz and replaces microcline (lower right). X 25.

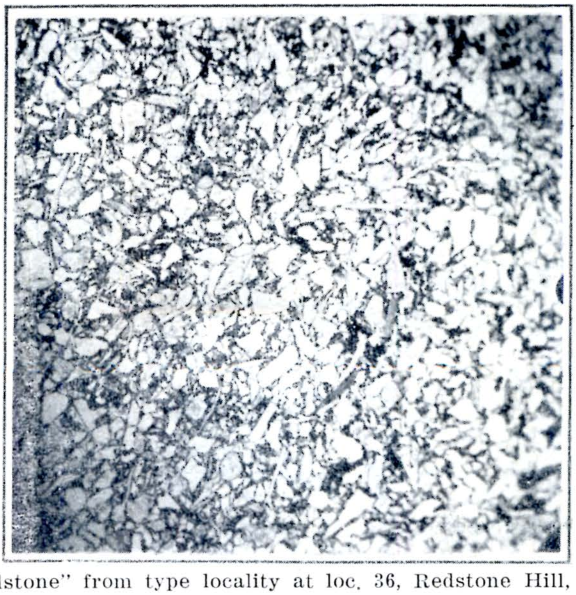


B.—Same as above, but with crossed nicols. Note extreme undulose extinction in the large quartz grain, X 25.

PLATE VII



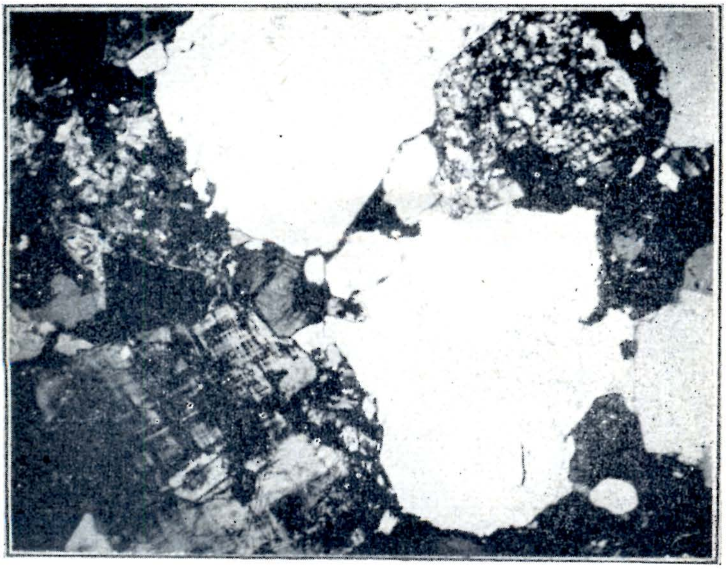
A.—Sericitized New Haven arkose, showing complete replacement of feldspars by sericite through contact metamorphic action, loc. 20, Mt. Sanford, very close to lower contact of West Rock sill. X 32.



B.—"Redstone" from type locality at loc. 36, Redstone Hill, central Connecticut. Note abundance of fresh biotite and large amount of hematitic clay. X 66.

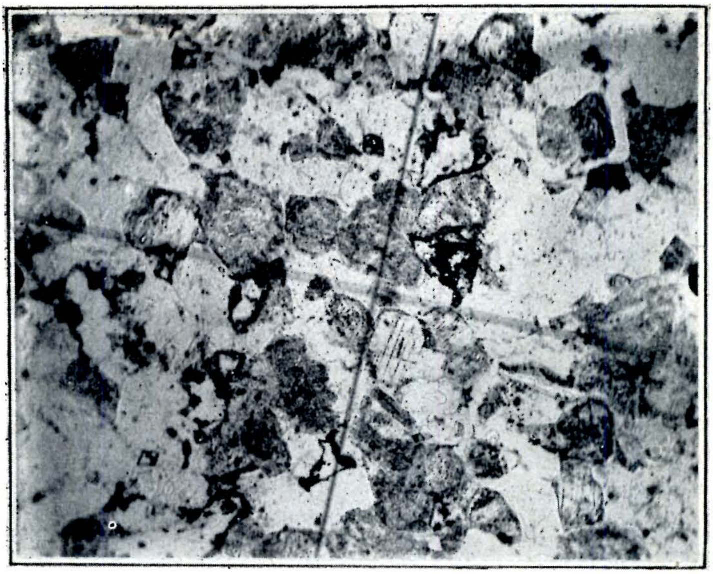
PLATE VIII

A.—Lower New Haven arkose from Bethany Gap (loc. 19), showing large quartz and microcline grains embedded in matrix of finer grains of similar composition and some kaolinic (?) clay. X 23.

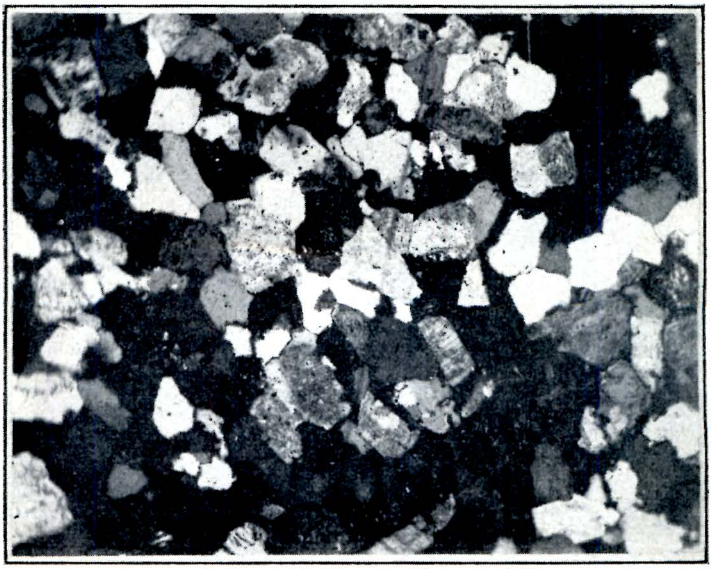


B.—Same as above, but in polarized light with crossed nicols.

PLATE IX



A.—Feldspathic sandstone from a relatively open-water phase of a swamp deposit of upper Meriden age; loc. 27, near Kensington (see also Figure 4). Photograph shows differential weathering of feldspars and secondary oxidation of granular siderite. X 46.



B.—Same as above, but with crossed nicols. X 60.

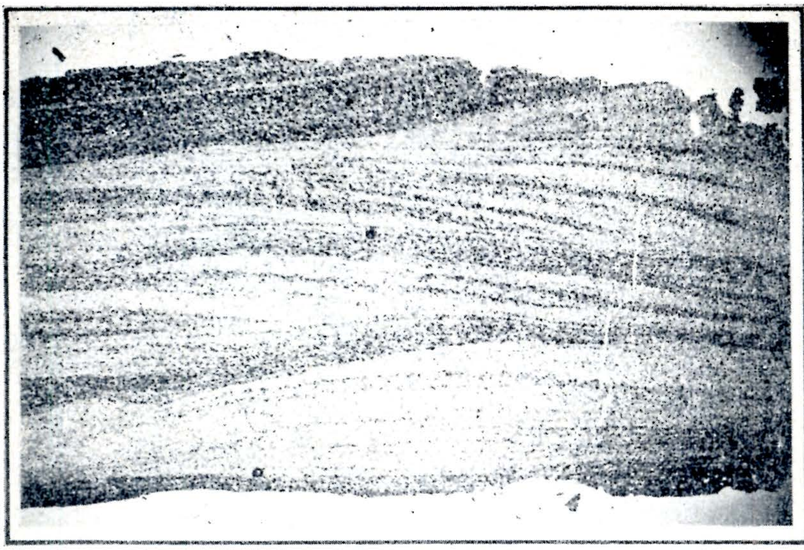
PLATE X

Sandstone dike (right) intruding into a trap sill (left). Both rocks are cut by a later calcite vein. Note orientation of elongated constituents of the arkose parallel to the contact, i.e., to the direction of flowage. One or two shreds of trap are incorporated into the arkose (upper half of photograph). Upper New Haven arkose, on Foxon Road. X 22.

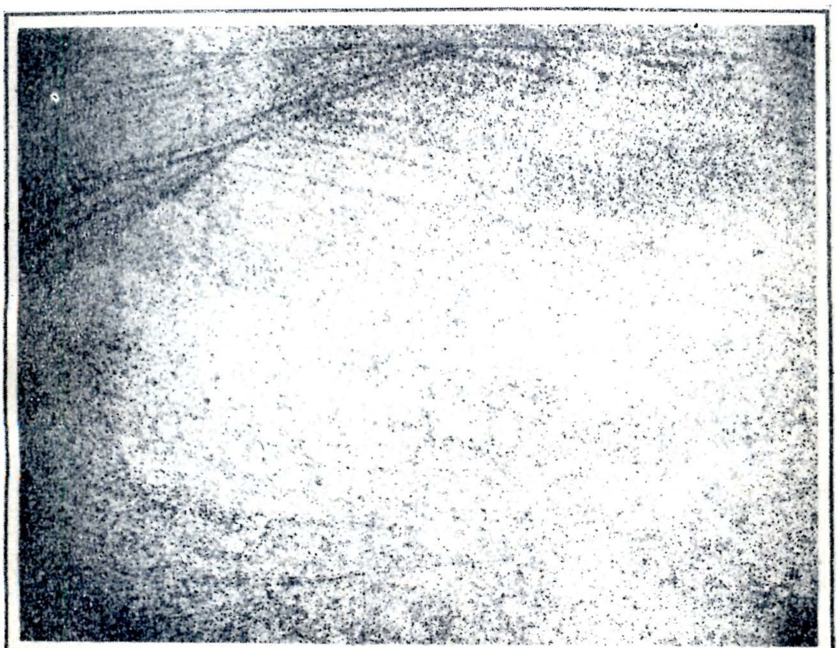
PLATE XI

Sandstone dike cutting trap sill, as in Plate X, but with crossed nicols. X 22.

PLATE XII

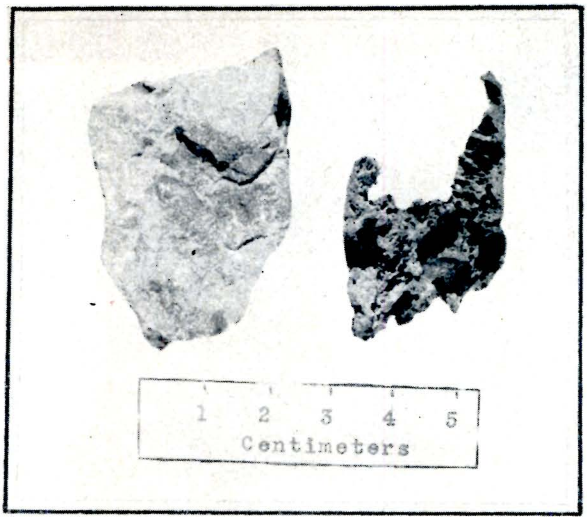


A.—Microbanding and cross-bedding in lacustrine silty shale from the Meriden formation, X 4 1/2.

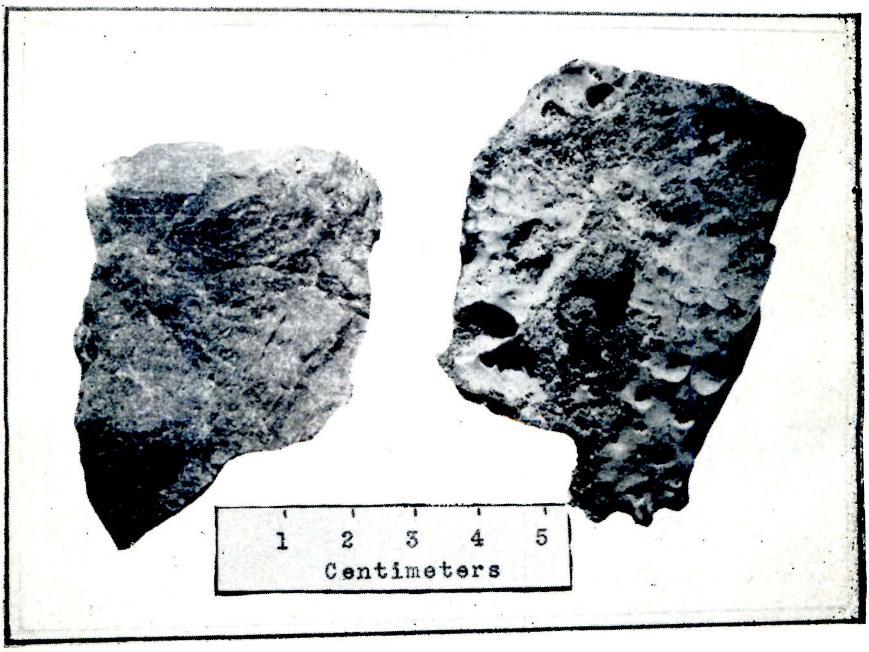


B.—Microscopic cut-and-fill stratification in dolomitic limestone, lower Meriden formation at Shuttle Meadow, central Connecticut, X 7 1/2.

PLATE XIII

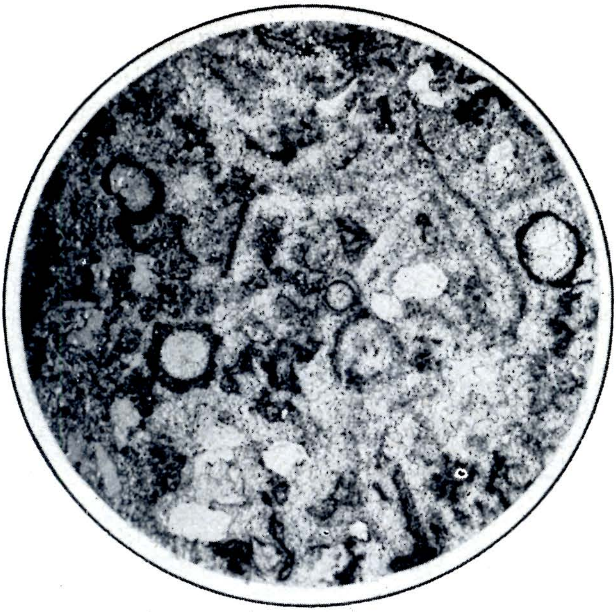


A.—Limestone from Shuttle Meadow, lower Meriden formation of central Connecticut: left—natural appearance; right—etched with hydrochloric acid.

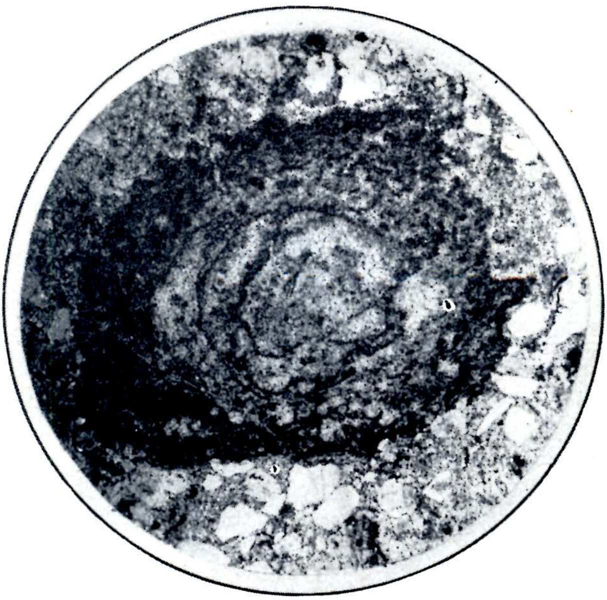


B.—Limestone from the Northford quarry, lower Meriden formation of southern Connecticut (loc. 9): left—natural appearance; right—after etching with hydrochloric acid. Note numerous sand grains.

PLATE XIV

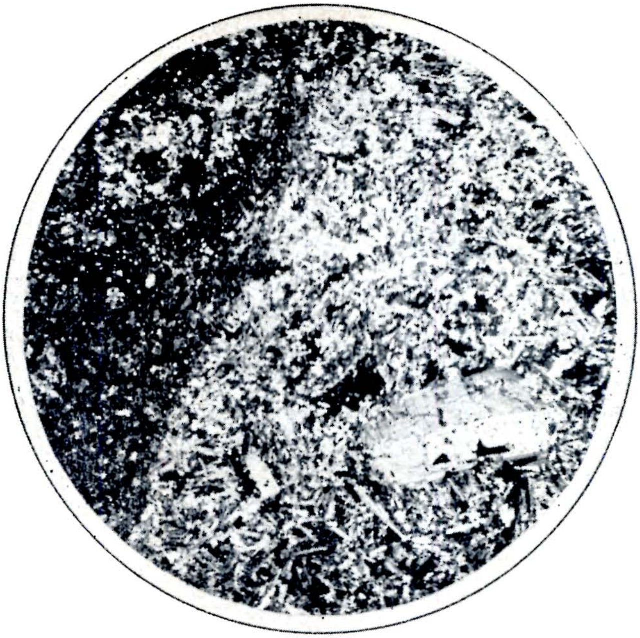


A.—Limestone showing round organic (?) bodies, presumably spores of Charophyta. Northford quarry (loc. 10), X 25.

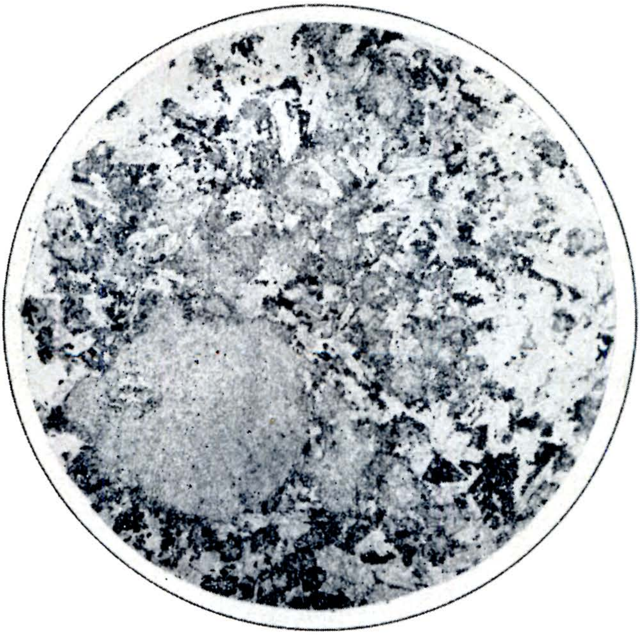


B.—Oval organic (?) body in limestone, presumably specimen of fresh-water alga. Northford quarry (loc. 10), X 25.

PLATE XV

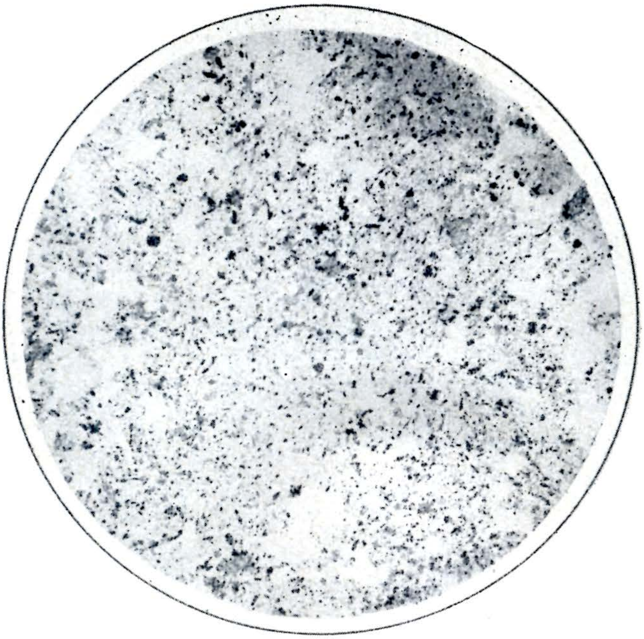


A.—Trap, 5 feet above lower contact of middle lava, Reed Gap (loc. 7). Crossed nicols. X 17.

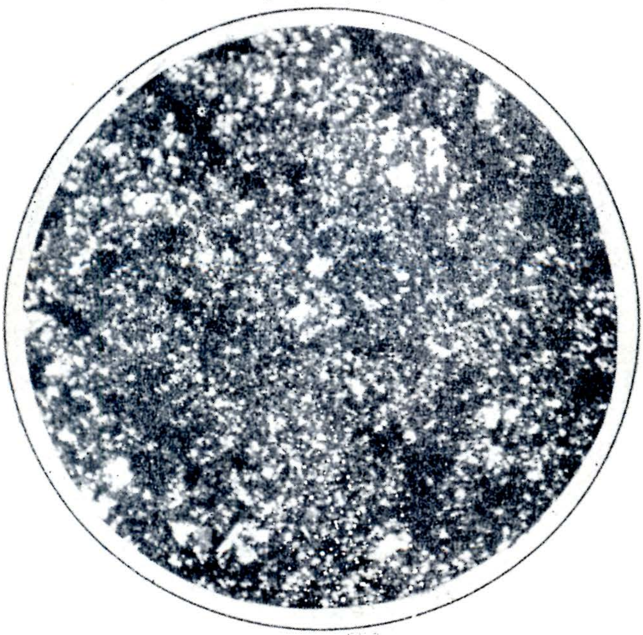


B.—As above; altered trap with calcite nodules one-half foot above contact. X 15.

PLATE XVI

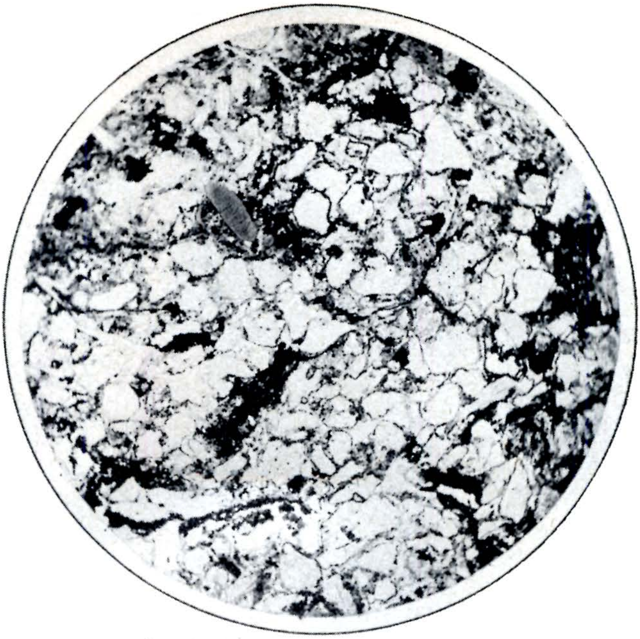


A.—Lower tuff (?) layer, 16 feet below lower contact of upper lava flow, upper Meriden formation; Reed Gap quarry (loc. 7), X 45.

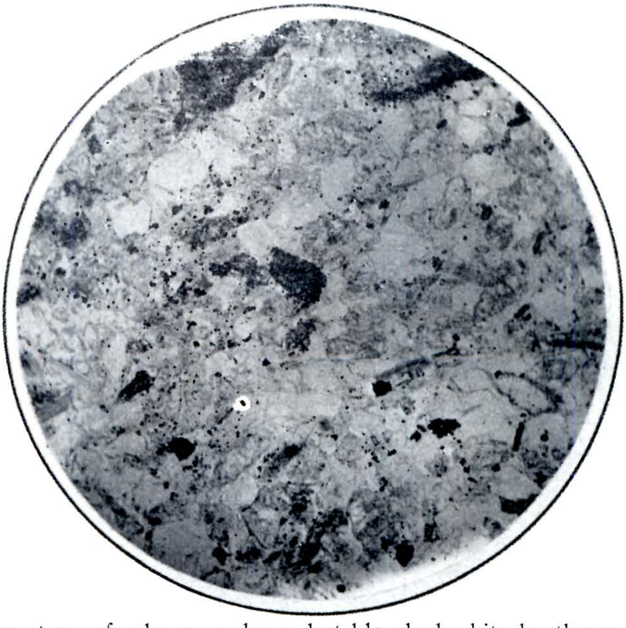


B.—As above, with crossed nicols, X 45. Note large amount of isotropic material.

PLATE XVII



A.—Normal, red-colored, fine-grained arkose, showing grains coated with red hematite (ferric oxide), which is also finely disseminated throughout rock matrix; 21 feet below contact of upper lava flow, Reed Gap quarry (loc. 7), X 45.



B.—Same type of arkose as above, but bleached white by thermal action of the upper lava flow. Four feet below flow contact hematite has been reduced to magnetite and is now concentrating in small or medium sized grains. Loc. 7. X 45.

PLATE XVIII

A.—Bleached arkose as on Plate XVII-B; crossed nicols, X 45.

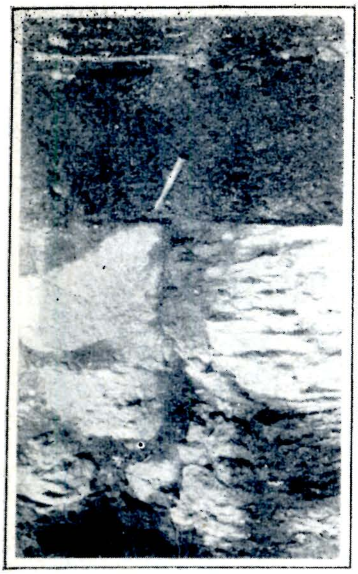
B.—Calcareous concretions in maroon siltstone; 10 feet below the upper lava flow, Reed Gap quarry (loc. 7). X 36.

PLATE XIX

A.—Detrital iron concretion in Portland arkose, loc. 23, X 18.

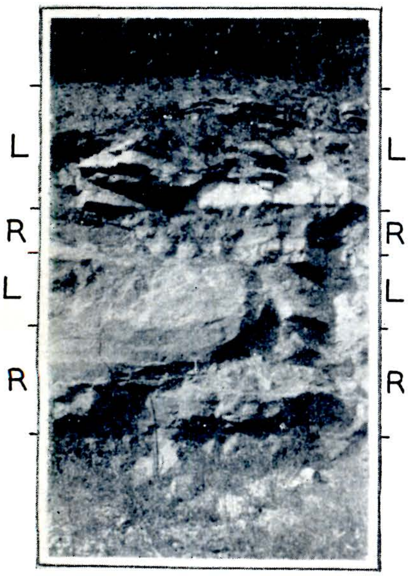
B.—Fanglomerate from Lake Quonnipaug, loc. 1. Shows a mixture of granitic detritus—quartz and feldspar—amidst larger fragments of the quartz—chlorite Bolton schist, X 5 1/2.

PLATES XX and XXI



A.—Lower New Haven arkose, loc. 17 on Shepard Avenue, Hamden. Shows coarse, pale purplish-gray arkose, underlain by red sandy siltstone facies.

B.—Contact between basal New Haven arkose and highly folded and injected crystalline Hartland schist below it, loc. 39 at Roaring Brook.

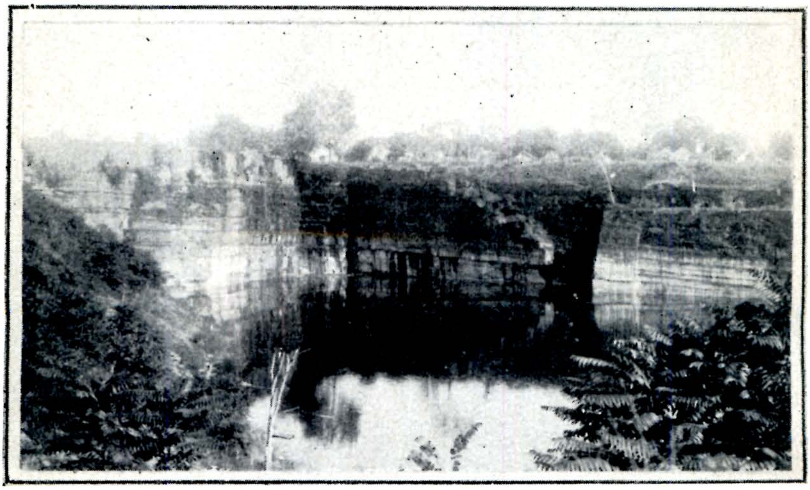


A.—Alternation between the Lamentation (coarse pale arkose) and Redstone (fine silty red sandstone) facies, at Hanover Pond, loc. 33A.

B.—Typical development of Lamentation arkose and conglomerate facies in the New Haven arkose of central Connecticut, loc. 34, Quinnipiac Gorge.

PLATE XXII

A.—Intraformational unconformity, showing erosion of Redstone facies by the Lamentation arkose facies. This is essentially the bottom of an ancient river channel cutting laterally across its own flood plain. From the upper New Haven arkose at Hanover Pond, central Connecticut.

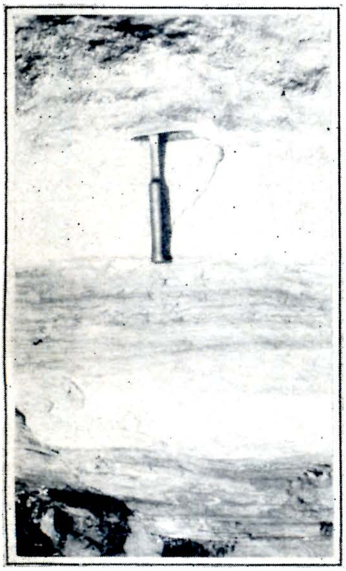


B.—Type locality of the Portland arkose, loc. 23, Second Portland quarry, near Middletown, central Connecticut. Note regional eastward dip of Triassic sedimentary prism.

PLATES XXIII and XXIV

A.—Lower Meriden lacustrine red beds, loc., 28, Hubbard Park near Meriden, central Connecticut.

B.—Upper Meriden swamp dark beds. Loc. 27, Kensington quarry, near Berlin, central Connecticut. (See also Figure 4.)

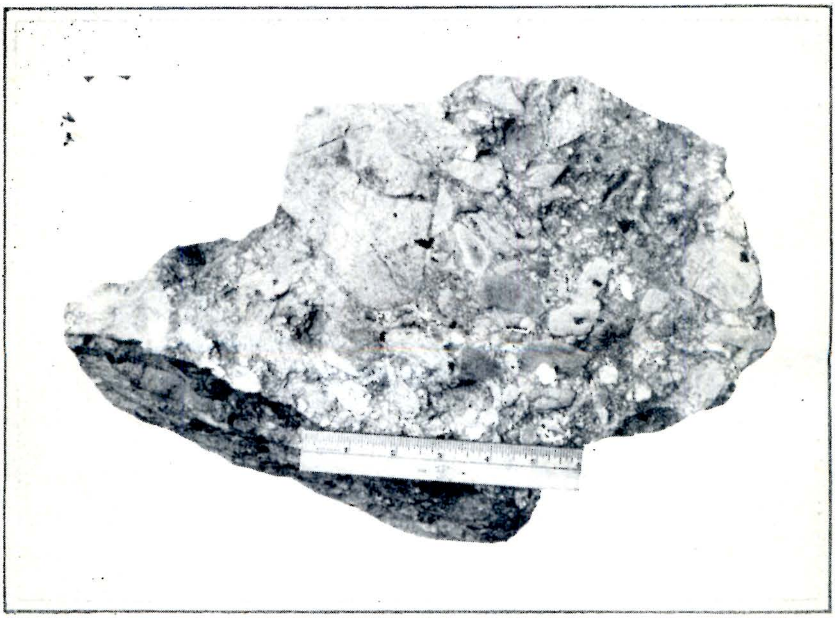


A.—Fine, dark siltstone interbedded with arkosic sand (at hammer) and fanglomerate (above hammer), loc. 1 at Lake Quonnipaug.

B.—Slickensiding and mineralization (calcite and barite) along fault plane in Lamentation arkose (above hammer) and to a minor extent in Redstone (below hammer). Hanover Pond, central Connecticut.

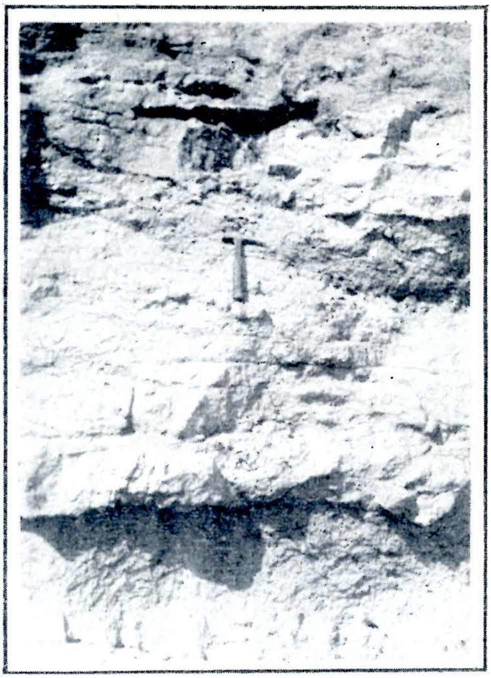
PLATE XXV

A.—Fanglomerate outcrop at East Portland, loc. 22, on N-S road, south of junction with Route 15-A. Outcrop is 30 feet thick, extends for 250 feet; average size of pebbles is 5 to 15 cm., some boulders go up to 45 cm. Interlayered, especially near top, with coarse arkosic sand. Outcrop approximately 650 feet (?) west of Great Fault.

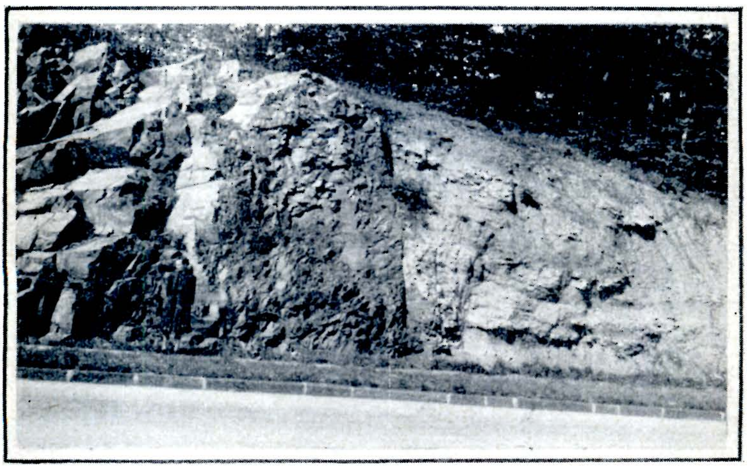


B.—Piece of fanglomerate from Lake Quonnipaug outcrop, very close to Great Fault. Surface of specimen polished by glacial action. Note granite and chlorite-schist pebbles.

PLATE XXVI

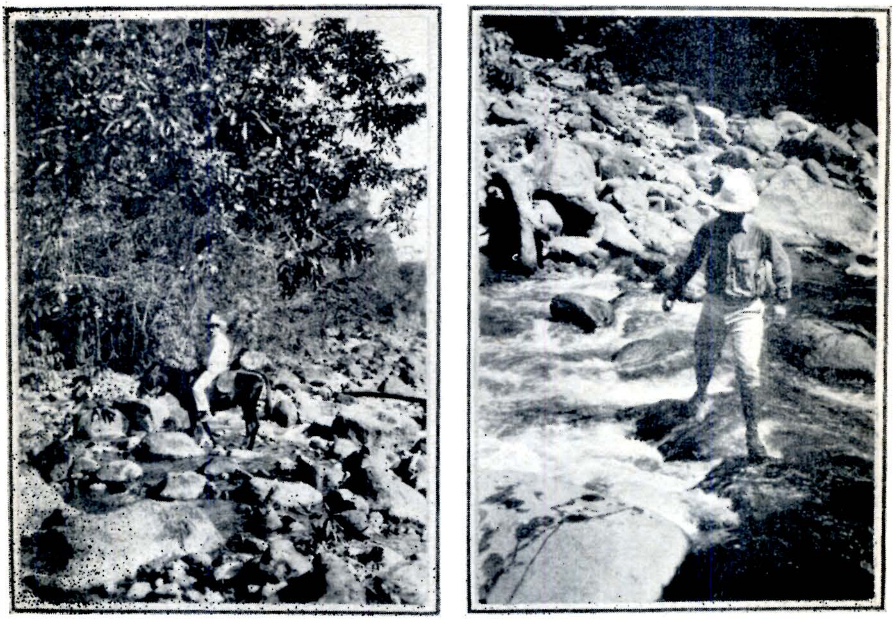


A.—Cross-bedded coarse arkose and conglomeratic lenses of upper New Haven age; detail from photograph of outcrop shown below on Plate XXVI-B.



B.—Vertical contact between intruding trap dike (left) and upper New Haven arkose (right). Outcrop is on west side of Whitney Avenue near New Haven-Hamden city line.

PLATE XXVII



EROSION AND SEDIMENTATION IN A TROPICAL FOOTHILL REGION

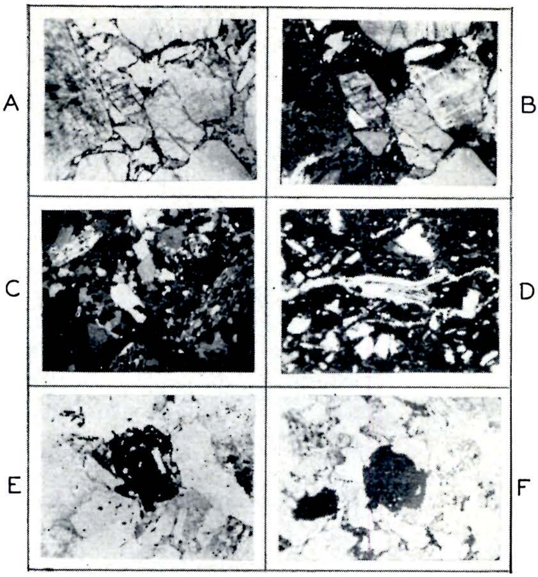
Fresh, coarse, angular boulders form small alluvial fans where a break in the slope interrupts the course of intermittent mountain torrents. Taken during the dry season in Chiapas (southern Mexico), a region with a rainfall of 200 inches per year. Average elevation of mountain tops over canyon floors around 500 feet.

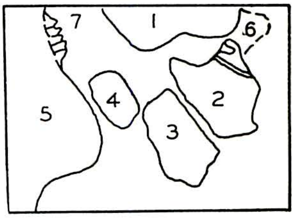
PLATE XXVIII

A.—Sedimentation on a tropical piedmont savanna. Dried-up bed of Mezcalapa River near the Chiapas-Tabasco boundary (southern Mexico) during the short dry season of a humid climate with a rainfall in excess of 100 inches per year. Channel, 3,000 feet wide, is covered with mud cracks and swept by sandstorms.

B.—Sedimentation on a tropical piedmont savanna. Alternation of pale gray, coarse, arkosic sands and finer-grained, reddish, clayey silts. Same general location and climatic conditions as above.

PLATE XXIX





A. and B.—Differential weathering of microcline within one single specimen. Note brilliantly fresh and translucent grain, 1; two fresh and almost unaltered grains, 2 and 3; a faintly altered grain, 4, and a deeply weathered kaolinized and reddened large grain, 5.

Note calcite nest at 6, filling cracks and eating into grain, 2.

Note small but very distinct and well developed overgrowth, 7, of secondary microcline growing out of the kaolinized grain, 5.

Specimens from loc. 13, upper New Haven arkose from Blakeslee quarry at Fair Haven; X 12; A-plain light, B-crossed nicols.

C.—Arkose from loc. 17, Shepard Avenue. Rather high in schist fragments, X 13.

D.—Red siltstone, loc. 17B, Shepard Avenue, interlayered with preceding rock (C), X 29. Note mixture of red hematitic and gibbsite-bearing clay with pieces of brilliantly fresh and unaltered feldspar (largest triangular grain) and very fresh biotite flakes.

E.—Detrital (transported) hematitic iron concretion ("perdigon") showing residual zonal arrangement at top suggested by semi-concentric arrangement of very small engulfed quartz grains, loc. 17 (same as C), Shepard Avenue, X 16.

F.—Detrital iron concretion from typical "brownstone" arkose, from the Portland quarry (loc. 23). Note nest of fractured garnet grains at right and immediately below concretion, X 18. In this particular specimen garnet forms almost 2 per cent of entire rock.

INDEX

Asterisks indicate illustrations.

State
Geological and Natural History Survey
of Connecticut

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69. Guide to the Insects of Connecticut. Part VI. The Diptera or True Flies of Connecticut. Third Fascicle: Asilidae or Robber Flies; by S. W. Bromley, Ph.D.; 51 pp., 2 pls., 38 figs., 23 cm., 1946. .75

70. Spiders of Connecticut; by B. J. Kaston, Ph.D.; 874 pp., 142 pls., 7 text figs., 1 map, 23 cm., 1948. 6.00

71. Twenty-second Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1945-1946; 23 pp., 23 cm., 1947. .20

72. Twenty-third Biennial Report of the Commissioners of the State Geological and Natural History Survey, 1947-1948; 16 pp., 23 cm., 1949 .20

73. The Petrography, Stratigraphy and Origin of the Triassic Sedimentary Rocks of Connecticut: by Paul D. Krynine, Ph.D., 264 pp., 41 figs. 29 pls., 1 Map in Pocket, 23 cm., 1950.

74. The Geology of Eastern Connecticut: by Wilbur G. Foye, Ph.D.; 100 pp., 25 figs., 1 pl., 23 cm., 1949. 1.00

75. Guide to the Insects of Connecticut. Part VI. The Diptera or True Flies of Connecticut. Fourth Fascicle. Family Tabanidae, by G. B. Fairchild. Family Phoridae, by C. T. Brues. 100 pp., 1 pl., 8 figs., 23 cm., 1950.

76. Preliminary Report on the Geology of the Mt. Prospect Complex; by Eugene N. Cameron. In Press

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MISCELLANEOUS SERIES

1. Rocks and Minerals of Connecticut; by Solon W. Stone; 16 pp., 23 cm., 1949. .20

2. An Exposure of the Triassic Eastern Border Fault; by Ralph E. Digman, Ph.D.; reprinted from American Journal of Science; vol. 248, pp. 37-45, 3 figs., 23 cm., 1950. .20

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CONNECTICUT

State Geological and Natural History Survey, Bulletin No. 73
The Petrography, Stratigraphy and Origin of the Triassic Sedimentary Rocks of Connecticut, by Paul D. Krynine; Hartford, 1950.
264 pp., 41 figs., 29 pls., 1 Map in Pocket, 23 cm.

KRYNINE, PAUL D.,

The Petrography, Stratigraphy and Origin of the Triassic Sedimentary Rocks of Connecticut, Hartford, 1950.
264 pp., 41 figs., 29 pls., 1 Map in Pocket, 23 cm.
(Bulletin No. 73, Connecticut Geological and Natural History Survey).

GEOLOGY

Krynine, Paul D., The Petrography, Stratigraphy and Origin of the Triassic Sedimentary Rocks of Connecticut, Hartford, 1950.
(Bulletin No. 73, Connecticut Geological and Natural History Survey).

TABLE 4A. TEXTURAL STUDY OF A SUITE OF TYPICAL TRIASSIC ROCKS FROM CONNECTICUT

					BULK COMPOSITION				MECHANICAL ANALYSIS OF INSOLUBLE SANDY FRACTION (EXCLUDING CLAY)								TOTAL GRADE SIZE DISTRIBUTION									CUMULATIVE GRADE SIZE DISTRIBUTION									TEXTURAL PARAMETERS			
		LOCALITY	Ref. Number	ROCK TYPE	Grains	Calcite cement	Red clay	White clay	Cobbles	Gravel	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Cobbles	Gravel	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	> 6.4	> 2.0	> 1.068	> 0.495	> 0.245	> 0.147	> 0.074	> 0.15	+ Clay	1st Quartile	Median	3rd Quartile	Sorting coefficient
SOUTHERN CONNECTICUT	PORTLAND	Lake Quonnipaug	1	Arkose	98	2	..	..	..	..	..	25	34	23	12	6	..	..	..	25	34	23	12	6	..	..	..	..	25	59	82	94	100	..	0.500	0.280	0.180	1.67
SOUTHERN CONNECTICUT	MERIDEN Upper	Branford, tunnel	2	Red arkose	92±	8±	..	..	..	..	..	32	34	14	12	8	..	..	..	32	34	14	12	8	..	..	..	..	32	66	80	92	100	—	0.570	0.358	0.184	1.76
SOUTHERN CONNECTICUT	MERIDEN Upper	Branford, tunnel	3	Arkose	77	23	..	..	..	..	..	37	31	15	10	3	..	..	..	37	31	15	10	3	..	..	..	..	37	68	83	93	96	—	0.61	0.368	0.200	1.75
SOUTHERN CONNECTICUT	MERIDEN Upper	N. Branford dam	4	Red siltstone	58	42—	?	..	..	..	..	12	40	20	13	15	..	..	..	12	40	20	13	15	..	..	..	..	12	52	72	85	100	—	0.385	0.253	0.129	1.73
SOUTHERN CONNECTICUT	MERIDEN Upper	N. Branford dam	5	Red siltstone	75	X	24	..	..	..	..	12	40	18	16	14	..	..	..	9	30	14	12	11	24	..	..	..	9	39	53	65	76	100	0.325	0.165	0.074	4.32
SOUTHERN CONNECTICUT	MERIDEN Upper	Totoket, N. E.	6	Arkose	91	..	..	9	..	..	..	30	45	14	7	4	..	..	..	27	41	13	6	4	9	..	..	..	27	68	81	87	91	100	0.52	0.340	0.190	1.65
SOUTHERN CONNECTICUT	MERIDEN Lower	Reed Gap	7	Feldsp. sandstone	90	..	..	10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
SOUTHERN CONNECTICUT	MERIDEN Lower	Totoket, S. W.	8	Red arkose	89	..	11	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
SOUTHERN CONNECTICUT	MERIDEN Lower	Northford quarry	9	Limestone	4	96	..	..	..	..	..	4	40	44	5	6	..	..	..	4	40	44	5	6	—	..	..	..	4	44	88	93	99	—	0.298	0.230	0.183	1.28
SOUTHERN CONNECTICUT	MERIDEN Lower	Northford quarry	10	Limestone	59	41	..	..	..	..	..	3	16	49	12	20	..	..	..	3	16	49	12	20	—	..	..	..	3	19	68	80	100	—	0.226	0.177	0.117	1.39
SOUTHERN CONNECTICUT	MERIDEN Lower	N. of Northford	11	Red arkose	93	..	7	..	9	11	27	21	16	6	2	8	8	10	25	20	15	6	2	7	7	8	18	43	63	78	84	86	93	100	1.69	0.84	0.290	2.41
SOUTHERN CONNECTICUT	NEW HAVEN	N. of Northford	12	Red arkose	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
SOUTHERN CONNECTICUT	NEW HAVEN	Fair Haven	13	Red arkose	94	2	4	..	..	5	30	35	13	6	6	5	..	5	29	33	12	6	5	5	4	..	5	34	67	79	85	90	95	99	1.240	0.795	0.32	1.97
SOUTHERN CONNECTICUT	NEW HAVEN	Mt. Carmel	14	Red arkose	89	..	11	..	1	9	34	29	20	4	1	1+	1	8	31	26	18	3	1	1	11	1	9	40	66	84	87	88	89	100	1.400	0.84	0.365	1.96
SOUTHERN CONNECTICUT	NEW HAVEN	Montowese	15	Red arkose	90	..	10	..	..	..	12	54	20	8	5	1	..	..	11	49	18	7	4	1	10	..	..	11	60	78	85	89	90	100	0.84	0.58	0.28	1.73
SOUTHERN CONNECTICUT	NEW HAVEN	Westwoods Ave.	16	Red arkose	94	..	6	..	13	25	27	17	10	4	1+	2	12	24	25	16	9	4	2	2	6	12	36	61	77	86	90	92	94	100	3.0	1.46	0.585	2.26
SOUTHERN CONNECTICUT	NEW HAVEN	Shepard Ave.	17	Arkose	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
SOUTHERN CONNECTICUT	NEW HAVEN	Dunbar Hill	18	Arkose	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
SOUTHERN CONNECTICUT	NEW HAVEN	Bethany Gap	19	Arkose	84	..	16	..	..	X	2	33	32	18	4	9	..	1	2	28	27	15	3	8	16	..	1	3	31	58	73	76	84	100	0.60	0.29	0.10	2.45
SOUTHERN CONNECTICUT	NEW HAVEN	Mt. Sanford	20	Arkose	94	..	..	6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
SOUTHERN CONNECTICUT	NEW HAVEN	Dawson Lake	21	Arkose	88	..	12	..	..	10	19	28	32	7	2	2	..	9	17	24	28	6	2	2	12	..	9	26	50	78	84	86	88	100	1.10	0.50	0.260	2.06
CENTRAL CONNECTICUT	PORTLAND	East Portland	22	Arkose	84	2	..	16	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CENTRAL CONNECTICUT	PORTLAND	Portland	23	Arkose	83	5	12	..	..	..	..	36	42	11	5	6	—	—	—	33	38	10	5	6	8	..	..	..	33	71	81	86	92	100	0.55	0.395	0.210	1.62
CENTRAL CONNECTICUT	PORTLAND	Cromwell	24	Redstone	69	..	31	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CENTRAL CONNECTICUT	PORTLAND	Westfield	25	Redstone	73	7	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CENTRAL CONNECTICUT	PORTLAND	Middlefield	26	Contact metam.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CENTRAL CONNECTICUT	MERIDEN U.	Kensington	27	Feldsp. sandstone	89	11	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CENTRAL CONNECTICUT	MERIDEN Lower	Hanging Hills	28	Red shale	69	..	31	..	..	..	..	..	15	30	22	33	..	..	..	..	10	21	15	23	31	..	..	..	..	10	31	46	69	100	0.174	0.055	0.012	3.81
CENTRAL CONNECTICUT	MERIDEN Lower	Shuttle Meadow	29	Sandy limestone	80	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CENTRAL CONNECTICUT	MERIDEN Lower	Shuttle Meadow	30	Red shale	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CENTRAL CONNECTICUT	MERIDEN Lower	Davis Orchard	31	Red siltstone	68	..	32	..	..	..	..	..	59	24	14	2	..	..	..	..	40	17	10	1	32	..	..	..	..	40	57	67	68	100	0.318	0.183	0.011	5.30
CENTRAL CONNECTICUT	NEW HAVEN	Lamentation Mt.	32	Red arkose	89	..	11	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CENTRAL CONNECTICUT	NEW HAVEN	Shuttle Gap	33	Red arkose	85	..	15	..	..	..	..	45	8	14	14	19	..	..	..	39	7	12	12	16	15	..	..	..	39	46	58	70	86	100	0.54	0.20	0.052	3.22
CENTRAL CONNECTICUT	NEW HAVEN	Quinnipiac Gorge	34	Arkose	94	4	..	2	..	21	41	25	6	2	2	1	..	21	41	25	6	2	2	1	2	..	21	62	87	93	95	97	98	100	1.92	1.32	0.780	1.57
CENTRAL CONNECTICUT	NEW HAVEN	Quinnipiac Gorge	35	Redstone	57	..	43	..	..	..	..	8	30	25	21	15	..	..	..	5	18	15	12	10	43	..	..	..	5	22	36	48	57	100	0.22	0.050	0.0118	4.32
CENTRAL CONNECTICUT	NEW HAVEN	Redstone Hill	36	Redstone	67	..	33	..	..	..	..	..	1	10	37	52	..	..	..	..	X	7	25	35	33	..	..	..	..	X	7	32	67	100	0.085	0.032	0.002	6.51
CENTRAL CONNECTICUT	NEW HAVEN	Bristol	37	Arkose	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CENTRAL CONNECTICUT	NEW HAVEN	Roaring Brook	38	Arkose	100—	..	..	X	..	3	21	51	17	4	3	2	..	3	21	51	17	4	3	2	..	..	3	24	75	91	95	98	100	..	1.05	0.735	0.485	1.47
CENTRAL CONNECTICUT	NEW HAVEN	Roaring Brook	39	Arkose	68	27	..	5	..	25	14	36	14	4	4	2	..	24	13	35	13	4	4	2	5	..	24	37	72	85	89	93	95	100	1.80	0.778	0.440	2.02
POMPERAUG	LOWER MERID.	Spring House	40	Red Shale	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
POMPERAUG	NEW HAVEN S. BRITAIN	Pine Hill	41	Red arkose	50±	20±	30±	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
POMPERAUG	NEW HAVEN S. BRITAIN	D. Mitchell Brook	42	Red arkose	90	..	10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
POMPERAUG	NEW HAVEN S. BRITAIN	Orenaug Hill	43	Redstone	70	..	30	..	..	..	..	..	30	43	21	6	..	..	..	..	21	30	15	4	30	..	..	..	..	21	51	66	70	100	0.24	0.15	0.005	6.93
POMPERAUG	NEW HAVEN S. BRITAIN	South Britain	44	Redstone	84	..	16	..	..	..	..	..	47	34	15	4	..	..	..	..	39	29	13	3	16	..	..	..	..	39	68	81	84	100	0.290	0.210	0.128	2.64
POMPERAUG	NEW HAVEN S. BRITAIN	N. Bear Hill	45	Arkose	93	..	..	7	..	..	2	40	35	13	7	2	..	..	2	37	33	12	7	2	7	..	..	2	39	72	84	91	93	100	0.760	0.368	0.225	1.84

X — Traces, below one percent

TABLE 4C. HEAVY MINERALS FROM THE CONNECTICUT TRIASSIC

Area	Division	Locality	Ref. Number	Indicolite	Epidote	Monazite	Kyanite	Hornblende	Staurolite	Sillimanite	Zoisite	Garnet	Ratio colorless to pink garnet	Rutile	Tourmaline	Zircon	Augite	Fluorite	Titanite	Tourmaline brown: pink: green	Anatase	Barite	Dolomite	Apatite	Chlorite	Xenotime	Micas	Iron Ores	Rare Minerals	Ratio Iron ores: Rare Minerals
				PERCENTAGE RATIO OF RARE NON-OPAQUE MINERALS OF HEAVY RESIDUE																							Percentage Ratio of Major Constituents of Heavy Residue			
SOUTHERN CONNECTICUT	PORTLAND	Lake Quonnipaug	1	..	..	..	..	..	..	..	..	P	..	..	P	..	..	..	..	..	..	..	..	..	..	..	99	..	..	..
SOUTHERN CONNECTICUT	MERIDEN Upper	Branford, tunnel	2	..	..	18	..	..	X	..	..	27	78:22	5	27	13	..	X	14	50:14:37	1	..	..	..	..	P	20	29	51	36:64
SOUTHERN CONNECTICUT	MERIDEN Upper	Branford, tunnel	3	..	..	4	..	..	..	..	..	91	70:30	1	2	1	..	..	..	85: 0:15	X	..	..	..	..	..	54	6	40	14:86
SOUTHERN CONNECTICUT	MERIDEN Upper	N. Branford dam	4	..	..	X	..	..	X	..	..	3	..	X	80	1	..	..	..	99: 0: 1	1	..	16	..	3	..	25	[66]	9	88:12
SOUTHERN CONNECTICUT	MERIDEN Upper	N. Branford dam	5	..	..	X	X	..	X	X	..	14	85:15	2	42	14	..	..	1	89: 4: 7	24	2	..	..	..	..	40	20	20	50:50
SOUTHERN CONNECTICUT	MERIDEN Upper	Totoket, N. E.	6	..	..	X	X	X	..	..	..	88	90:10	1	2	3	..	..	..	20:10:70	1	5	..	X	..	X	27	26	47	36:64
SOUTHERN CONNECTICUT	MERIDEN Lower	Reed Gap	7	..	..	1	..	..	X	..	..	X	..	1	72	11	..	..	..	0:80:20	15	..	P	..	..	..	44	47	9	84:16
SOUTHERN CONNECTICUT	MERIDEN Lower	Totoket, S. W.	8	..	..	X	..	X	2	..	..	X	..	2	72	5	..	..	1	67: 6:26	16	..	..	..	..	..	99	X	X	99:51
SOUTHERN CONNECTICUT	MERIDEN Lower	Northford quarry	9	X	X	X	1	..	1	..	..	1	X	3	77	8	..	X	3	15:30:45	5	(82)	..	..	..	..	15	44	41	52:49
SOUTHERN CONNECTICUT	MERIDEN Lower	Northford quarry	10	X	..	3	..	X	X	..	..	X	..	9	38	32	..	..	3	30:20:50	3	12	..	..	..	..	19	33	48	41:59
SOUTHERN CONNECTICUT	MERIDEN Lower	N. of Northford	11	X	X	2	1	..	X	..	..	1	..	1	40	19	..	..	18	35:30:35	6	10	..	..	..	..	14	58	28	67:33
SOUTHERN CONNECTICUT	NEW HAVEN	N. of Northford	12	..	1	..	X	..	X	..	..	64	58:42	X	5	3	..	..	8	50:20:30	10	1	..	..	..	..	14	35	51	41:59
SOUTHERN CONNECTICUT	NEW HAVEN	Fair Haven	13	..	..	15	..	..	..	X	..	1	..	3	29	51	..	..	4	14:14:72	1	..	..	..	..	P	36	43	21	68:32
SOUTHERN CONNECTICUT	NEW HAVEN	Mt. Carmel	14	..	12	..	..	..	2	..	X	67	64:36	..	8	3	2	..	3	35: 5:60	X	X	..	..	..	..	20	14	66	18:82
SOUTHERN CONNECTICUT	NEW HAVEN	Montowese	15	..	4	7	..	1	2	X	X	62	66:34	..	5	2	..	..	3	50:17:33	4	(39)	..	..	..	..	12	25	63	28:82
SOUTHERN CONNECTICUT	NEW HAVEN	Westwoods Ave.	16	..	X	..	X	..	1	..	..	78	75:25	X	4	1	..	12	2	40:20:40	X	X	..	..	..	..	9	9	82	10:90
SOUTHERN CONNECTICUT	NEW HAVEN	Shepard Ave.	17	..	..	..	..	..	..	..	..	74	77:23	2	9	2	..	..	X	60: 7:33	5	X	..	..	6	X	30	36	34	51:49
SOUTHERN CONNECTICUT	NEW HAVEN	Dunbar Hill	18	..	20	1	2	..	6	..	2	48	64:36	1	4	6	..	..	5	40:10:50	X	6	..	..	1	1	7	23	68	30:70
SOUTHERN CONNECTICUT	NEW HAVEN	Bethany Gap	19	X	5	..	4	5	5	..	2	24	95: 5	4	29	9	..	15	3	62:18:20	X	..	..	..	..	..	18	30	42	42:58
SOUTHERN CONNECTICUT	NEW HAVEN	Mt. Sanford	20	..	1	..	3	9	10	X	1	21	60:40	2	1	33	X	..	9	—:—: X	6	X	..	X	X	..	6	45	49	54:46
SOUTHERN CONNECTICUT	NEW HAVEN	Dawson Lake	21	X	33	..	2	3	3	..	1	26	33-67	2	22	7	..	..	..	55: 0:55	X	..	..	..	..	..	18	35	47	43:57
CENTRAL CONNECTICUT	PORTLAND	East Portland	22	1	13	..	..	1	..	..	2	71	84:16	1	10	X	..	..	1	76: 4:20	..	..	..	..	X	..	14	21	65	24:76
CENTRAL CONNECTICUT	PORTLAND	Portland	23	2	..	..	..	..	..	X	..	73	76:24	3	17	..	..	..	1	85: 9: 6	2	..	..	..	X	..	7	22	71	23:77
CENTRAL CONNECTICUT	PORTLAND	Cromwell	24	1	..	..	..	..	..	..	..	56	98: 2	12	30	1	..	..	..	87: 2:12	..	..	..	..	X	..	11	24	65	27:73
CENTRAL CONNECTICUT	PORTLAND	Westfield	25	2	..	..	..	..	..	..	..	56	96: 4	2	36	X	..	..	..	93: 2: 5	2	..	..	..	X	..	10	14	76	16:84
CENTRAL CONNECTICUT	PORTLAND	Middlefield	26	P	..	..	..	..	..	..	..	P	..	P	P	..	..	..	..	..	P	P	..	..	..	..	..	99	..	99: 1
CENTRAL CONNECTICUT	MERIDEN U.	Kensington	27	5	..	2	..	..	..	..	..	X	..	19	67	6	X	..	X	89: 1:10	(11)	(26)	X	..	..	X	..	..	..	..
CENTRAL CONNECTICUT	MERIDEN Lower	Hanging Hills	28	X	2	..	X	X	14	X	2	43	..	2	2	9	..	..	1	..	3	18	..	..	4	..	..	..	..	..
CENTRAL CONNECTICUT	MERIDEN Lower	Shuttle Meadow	29	1	..	..	..	..	4	X	..	X	..	10	43	28	X	1	..	84: 4:12	8	50°	..	..	..	..	30	15	45	25:75
CENTRAL CONNECTICUT	MERIDEN Lower	Shuttle Meadow	30	1	..	..	X	..	4	..	2	X	..	8	46	27	..	..	2	67: 1:32	3	3	..	..	2	..	0	50	50	50:50
CENTRAL CONNECTICUT	MERIDEN Lower	Davis orchard	31	X	2	1	1	6	1	..	..	2	..	12	37	7	X	..	2	35:35:30	4	(24)	..	..	..	..	33	15	52	22:78
CENTRAL CONNECTICUT	NEW HAVEN	Lamentation Mt.	32	4	..	2	..	..	..	..	..	2	80:20	6	64	15	..	..	1	89: 6: 5	5	..	..	..	X	..	15	38	47	44:56
CENTRAL CONNECTICUT	NEW HAVEN	Shuttle Gap	33	1	..	2	X	..	..	..	..	6	75:25	5	56	14	..	..	1	85: 4:11	5	..	..	..	..	..	8	48	44	52:48
CENTRAL CONNECTICUT	NEW HAVEN	Quinnipiac Gorge	34	2	..	1	..	..	..	X	..	54	95: 5	4	23	10	..	..	..	80: 8:12	..	..	..	..	3	..	..	..	..	..
CENTRAL CONNECTICUT	NEW HAVEN	Quinnipiac Gorge	35	1	..	1	X	..	..	X	..	56	98: 2	7	23	12	..	..	..	87: 4: 9	..	..	..	..	1	..	20	23	56	27:73
CENTRAL CONNECTICUT	NEW HAVEN	Redstone Hill	36	2	..	..	..	..	X	X	..	42	90:10	3	47	2	..	..	X	93: 3: 4	X	..	..	..	X	..	4	9	91	10:90
CENTRAL CONNECTICUT	NEW HAVEN	Bristol	37	X	X	..	X	10	3	1	X	2	100: 0	5	46	17	2	1	6	74: 6:20	..	..	..	..	..	..	65	30	5	86:14
CENTRAL CONNECTICUT	NEW HAVEN	Roaring Brook	38	17	X	..	..	1	5	..	..	X	100: 0	2	52	12	13	..	3	50:25:25	X	(63)	..	..	X	..	5	38	57	40:60
CENTRAL CONNECTICUT	NEW HAVEN	Roaring Brook	39	21	7	..	4	X	12	..	..	..	60:40	3	29	15	15	..	3	96: 0: 4	2	6	..	..	..	..	28	43	29	59:41
POMPERAUG	LOWER MERID.	Spring House	40	..	..	X	X	..	2	..	..	12	100: 0	5	5	74	..	X	1	10: 0:90	..	X	..	..	..	..	13	67	20	77:23
POMPERAUG	NEW HAVEN S. BRITAIN	Pine Hill	41	..	..	X	..	..	1	..	..	77	..	3	6	14	..	..	X	73:23: 4	X	..	..	..	..	..	5	45	50	47:53
POMPERAUG	NEW HAVEN S. BRITAIN	D. Mitchell Brook	42	1	..	1	X	..	X	..	..	60	92: 8	3	25	8	..	..	X	80: 4:16	1	..	..	..	..	..	7	17	76	19:81
POMPERAUG	NEW HAVEN S. BRITAIN	Orenaug Hill	43	2	X	2	X	X	1	..	..	2	100: 0	6	64	20	X	..	1	93: 4: 4	X	X	..	..	..	..	6	48	46	51:49
POMPERAUG	NEW HAVEN S. BRITAIN	South Britain	44	X	X	5	..	X	X	..	..	45	96: 4	3	32	9	..	..	1	90: 3: 7	4	..	..	..	..	X	4	54	42	56:44
POMPERAUG	NEW HAVEN S. BRITAIN	N. Bear Hill	45	9	X	3	X	1	2	..	..	43	76:24	5	31	4	..	..	..	48:23:30	1	X	..	..	..	..	8	42	50	45:55

X — traces, less than 1%
P — present, not quantitatively determined
° — ratio to total heavy residue

( ) — Ratio to rare minerals; this ratio subtracted and balance of rare minerals recomputed on a 100% basis.
[ ] — Entire pyrite

TABLE 4B. PETROGRAPHIC STUDY OF A SUITE OF TYPICAL TRIASSIC ROCKS FROM CONNECTICUT

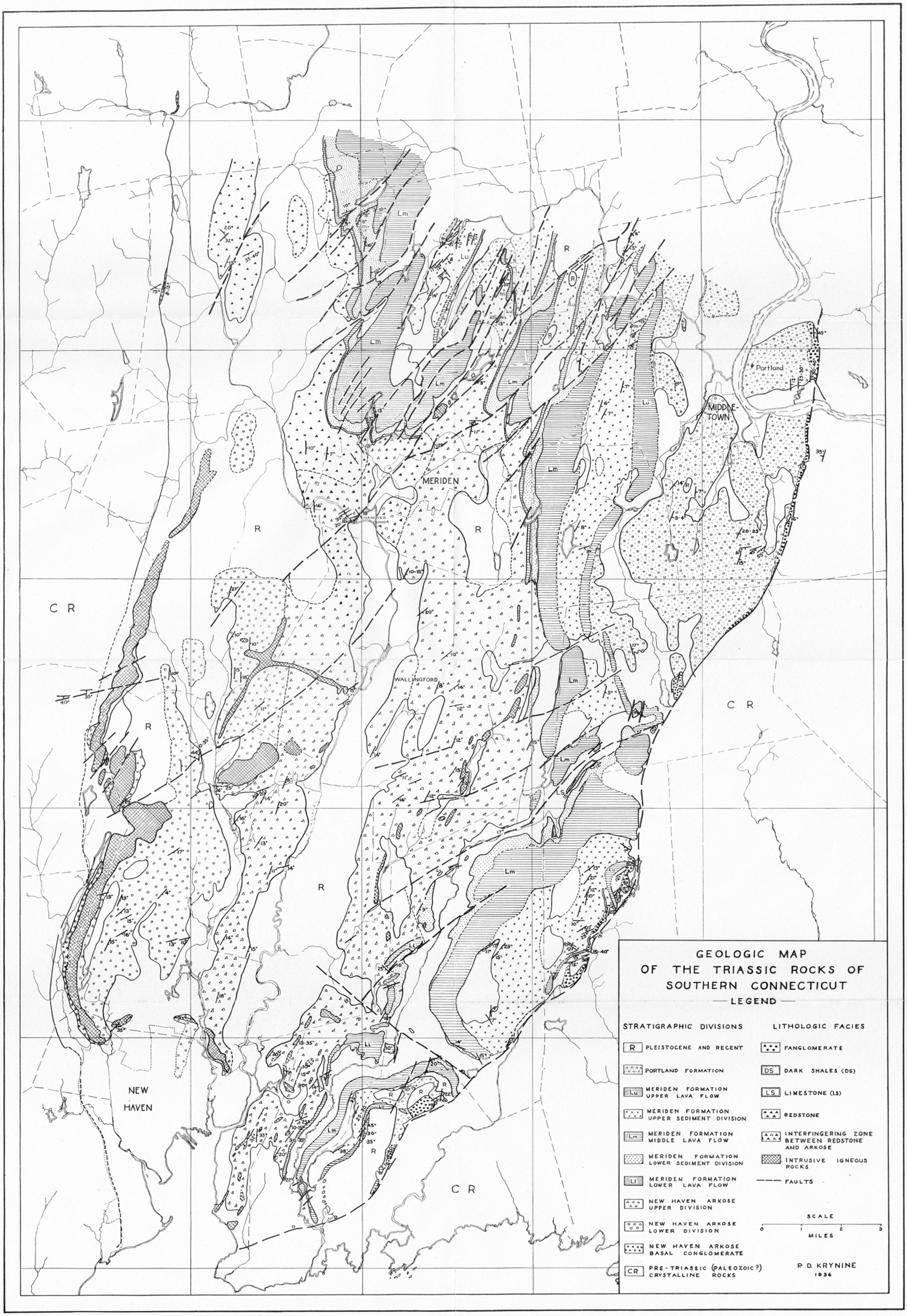
						TOTAL COMPOSITION								RATIOS WITHIN GRAINS (MATRIX EXCLUDED)				DETAILS			
			LOCALITY	Ref. Number	ROCK TYPE	Quartz	Microcline (+ some Orthoclase)	Plagioclase	Micas	(Hematitic Clay + Silt)	(Kaolin + ± Sericite)	Calcite	Others	Quartz	Feldspars	Micas	K-Feldspar: :Plagioclase	Dominant Plagioclase	Dominant Mica	Authigenic Silicates	LOCATION
SOUTHERN CONNECTICUT	PORTLAND		Lake Quonnipaug	1	Arkose	43	34°	16	5	..	..	2	..	44	51	5	70:30	SO	B	q,m(?)	Near major fault
SOUTHERN CONNECTICUT	MERIDEN	Upper	Branford, tunnel	2	Red arkose	40	31	7	3	8	..	8	2	50	47	3	85:15	AB	B	q,m,ab	Near major fault
SOUTHERN CONNECTICUT	MERIDEN	Upper	Branford, tunnel	3	Arkose	33	21	19	4	..	..	23	..	43	52	5	58:42	SO	B	..	Paludal or lacustrine
SOUTHERN CONNECTICUT	MERIDEN	Upper	N. Branford dam	4	Red siltstone	40±	5±	10±	25±	15	..	5	..	50±	20±	30±	35:65	SO	M	q,m	Near major fault
SOUTHERN CONNECTICUT	MERIDEN	Upper	N. Branford dam	5	Red siltstone	37±	18±	12±	5	25±	..	3	..	50±	40±	10±	60:40	AB	M	..	Near major fault
SOUTHERN CONNECTICUT	MERIDEN	Upper	Totoket, N. E.	6	Arkose	22	53	10	5	..	9	..	..	25	70	5	85:15	AB	B	..	Normal
SOUTHERN CONNECTICUT	MERIDEN	Lower	Reed Gap	7	Feldsp. sandstone	41	21°	21	4	..	..	2	10	47	49	4	50:50	AB	M	q,ab	3 feet below middle lava flow
SOUTHERN CONNECTICUT	MERIDEN	Lower	Totoket, S. W.	8	Red arkose	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Normal
SOUTHERN CONNECTICUT	MERIDEN	Lower	Northford quarry	9	Limestone	5+	2—	1—	..	..	..	93	..	72	28	..	70:30	SO	M	q	Lacustrine deposit
SOUTHERN CONNECTICUT	MERIDEN	Lower	Northford quarry	10	Limestone	25	24	6	4	..	..	41	..	41	52	7	80:20	SO	M	..	Lacustrine deposit
SOUTHERN CONNECTICUT	MERIDEN	Lower	N. of Northford	11	Red arkose	40	40	10	3	7	..	..	..	43	54	3	80:20	AB	B	..	Normal
SOUTHERN CONNECTICUT	NEW HAVEN		N. of Northford	12	Red arkose	60	23	13	1	—5—		..	..	62	37	1	65:35	AB	..	..	Normal
SOUTHERN CONNECTICUT	NEW HAVEN		Fair Haven	13	Red arkose	55	38	2	1	4	..	2	..	57	42	1	95:5	SO	M	..	Normal
SOUTHERN CONNECTICUT	NEW HAVEN		Mt. Carmel	14	Red arkose	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Normal
SOUTHERN CONNECTICUT	NEW HAVEN		Montowese	15	Red arkose	56	–34–	..	?	10	..	..	..	62	38	?	?	..	..	..	Normal
SOUTHERN CONNECTICUT	NEW HAVEN		Shepard Ave.	17	Arkose	49	10	16	5	..	13	..	8	61	33	6	37:63	OL	B	..	Normal
SOUTHERN CONNECTICUT	NEW HAVEN		Shepard Ave.	17b	Red siltstone	31	8	3	8	50	..	..	..	62	22	16	50:50	SO	M	..	Normal
SOUTHERN CONNECTICUT	NEW HAVEN		Dunbar Hill	18	Arkose	60	30	4	X	..	5	..	1	63	37	X	89:11	AB	..	..	Normal
SOUTHERN CONNECTICUT	NEW HAVEN		Bethany Gap	19	Arkose	50	26	5	3	–16–		..	..	60	37	3	80:20	AB	M	..	Normal
SOUTHERN CONNECTICUT	NEW HAVEN		Mt. Sanford	20	Arkose	72	..	..	..	..	28	..	..	72	+++	..	..	..	..	..	Below West Rock sill
SOUTHERN CONNECTICUT	NEW HAVEN		Dawson Lake	21	Arkose	80	6	2	1	–10–		..	..	88	11	1	80:20	SO	M	..	Normal
CENTRAL CONNECTICUT	PORTLAND		East Portland	22	Arkose	..	..	..	..	..	..	..	..	..	..	..	..	..	..	q	Near Great Fault
CENTRAL CONNECTICUT	PORTLAND		Portland	23	Arkose	29	50	11	4	6	..	..	2	31	65	4	85:15	SO	BC	..	Normal
CENTRAL CONNECTICUT	PORTLAND		Cromwell	24	Redstone	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Normal
CENTRAL CONNECTICUT	PORTLAND		Westfield	25	Redstone	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Normal
CENTRAL CONNECTICUT	PORTLAND		Middlefield	26	Arkose	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1 foot below upper lava flow
CENTRAL CONNECTICUT	MERIDEN		Kensington	27	Feldsp. sandstone	52	13°	30	X	..	..	..	5	55	45	X	30:70	AB	..	q,ab	Lacustrine deposit
CENTRAL CONNECTICUT	MERIDEN	Lower	Hanging Hills	28	Red shale	30±	10±	10±	20±	30±	..	..	..	45	25	30	?	?	M	..	Normal
CENTRAL CONNECTICUT	MERIDEN	Lower	Shuttle Meadow	29	Silty limestone	45±	4±	1±	..	..	..	35	15	90	10	..	80:20	?	M	q	Lacustrine deposit
CENTRAL CONNECTICUT	MERIDEN	Lower	Shuttle Meadow	30	Red shale	30±	30±	10±	..	30±	..	..	..	43	43	14	60:40	?	M	..	Normal
CENTRAL CONNECTICUT	MERIDEN	Lower	Davis Orchard	31	Red siltstone	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Normal
CENTRAL CONNECTICUT	NEW HAVEN		Lamentation Mt.	32	Red arkose	44	30	17	1	10	..	..	..	47	52	1	60:40	AB	M	q,m,ab	Directly below lower lava flow
CENTRAL CONNECTICUT	NEW HAVEN		Shuttle Gap	33	Red arkose	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Normal
CENTRAL CONNECTICUT	NEW HAVEN		Quinnipiac Gorge	34	Arkose	..	..	..	..	..	2	4	..	..	..	..	..	..	..	..	Normal
CENTRAL CONNECTICUT	NEW HAVEN		Quinnipiac Gorge	35	Redstone	..	..	..	..	43	..	X	..	..	..	..	..	..	..	..	Normal
CENTRAL CONNECTICUT	NEW HAVEN		Redstone Hill	36	Redstone	34	29	14	10	33	..	X	..	50	35	15	40:60	AB	M	..	Normal
CENTRAL CONNECTICUT	NEW HAVEN		Bristol	37	Arkose	74	16	1	..	–9–		..	..	78	22	..	95:5	AB	M	..	Normal
CENTRAL CONNECTICUT	NEW HAVEN		Roaring Brook	38	Arkose	82	5	X	5	–8–		..	..	88	6	6	95:5	AB	M	..	Normal
CENTRAL CONNECTICUT	NEW HAVEN		Roaring Brook	39	Arkose	50	16	3	1	..	3	27(+)	..	73	26	1	85:15	AB	M	..	Near major fault
POMPERAUG	LOWER MERID.		Spring House	40	Brown + dark shale	35±	–15–	..		30±	..	20	..	45	17	38	?	?	B	..	Lacustrine deposit
POMPERAUG	NEW HAVEN S. BRITAIN		Pine Hill	41	Red arkose	28	32	3	X	7	..	30	..	44	56	X	92:8	AB	B	..	Near major fault
POMPERAUG	NEW HAVEN S. BRITAIN		D. Mitchell Brook	42	Red arkose	..	..	..	..	10	..	..	..	..	..	..	..	..	..	..	Normal
POMPERAUG	NEW HAVEN S. BRITAIN		Orenaug Hill	43	Redstone	37	15	10	7	31	..	..	..	52	38	10	60:40	AB	M	..	Normal
POMPERAUG	NEW HAVEN S. BRITAIN		South Britain	44	Redstone	39	6	31	6	16	..	..	2	47	46	7	20:80	AB	B	..	Normal
POMPERAUG	NEW HAVEN S. BRITAIN		N. Bear Hill	45	Arkose	51	30	X	2	..	7	..	10	62	36	2	99:1	AB	M	..	Normal

AB — Detrital albite
SO — Detrital sodic oligoclase
OL — Detrital oligoclase

B — Detrital biotite
M — Detrital muscovite
C — Detrital chlorite

° — Orthoclase predominates over microcline
+++ — Feldspar entirely replaced by sericite
(+) — Feldspar largely replaced by calcite

q — Authigenic (secondary) quartz
m — Authigenic (secondary) microcline
ab — Authigenic (secondary) albite


GEOLOGIC MAP
OF THE TRIASSIC ROCKS OF
SOUTHERN CONNECTICUT
— LEGEND —
STRATIGRAPHIC DIVISIONS
R PLEISTOCENE AND RECENT
PORTLAND FORMATION
Lu MERIDEN FORMATION UPPER LAVA FLOW
MERIDEN FORMATION UPPER SEDIMENT DIVISION
Lm MERIDEN FORMATION MIDDLE LAVA FLOW
MERIDEN FORMATION LOWER SEDIMENT DIVISION
Ll MERIDEN FORMATION LOWER LAVA FLOW
NEW HAVEN ARKOSE UPPER DIVISION
NEW HAVEN ARKOSE LOWER DIVISION
NEW HAVEN ARKOSE BASAL CONGLOMERATE
CR PRE-TRIASSIC (PALEOZOIC?) CRYSTALLINE ROCKS
LITHOLOGIC FACIES
FANGLOMERATE
DS DARK SHALES (DS)
LS LIMESTONE (LS)
REDSTONE
INTERFINGERING ZONE BETWEEN REDSTONE AND ARKOSE
INTRUSIVE IGNEOUS ROCKS
FAULTS
SCALE
0 1 2 3
MILES
P. D. KRYNINE
1936
MERIDEN
WALLINGFORD
MIDDLE-TOWN
Portland
NEW HAVEN
HANOVER POND
CR
R